ECONOMIC GEOLOGY

WITH WHICH IS INCORPORATED

THE AMERICAN GEOLOGIST

VOL. XIII JANUARY, 1918 NO. 1

GEOLOGY AND ORE DEPOSITS OF THE COLLBRAN CONTACT OF THE SUAN MINING CONCESSION, KOREA.[1]

D. F. HIGGINS.

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INTRODUCTION.

In the Suan Mining Concession granitic intrusions have intensely metamorphosed a series of sedimentary rocks and resulted in the formation of deposits of copper, bismuth and gold. Some of the phenomena associated with the intrusion, metamorphism, and ore deposition are considered in this paper.

[1] Published with the permission of the Seoul Mining Company.

The general location of the Suan Mining District is in Central Korea (Fig. 1), about fifty-five miles east-south-east of the city of Pyeng Yang, Korea, approximately in latitude 38° 48′ north, and longitude 120° 20′ east. The Suan Mining Concession held

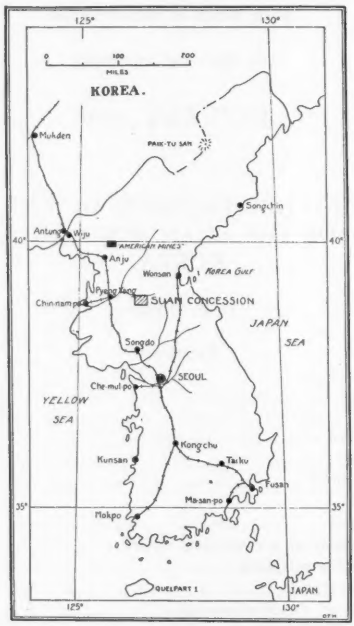


FIG. 1. Map of Korea showing the general location of the Suan Mining Concession and the principal towns.

by the Seoul Mining Company (recently seized) covers an area of 40 by 60 Korean *li*, about 260 square miles. The camps are reached by government and company roads from Pyeng Yang. The generally rugged nature of the topography of the concession is indicated in Plate I., *A*. The maximum difference of elevation on the concession is about 3,500 feet. The climate blends the characteristics of semi-tropical and north temperate conditions.

There is a rather heavy rainfall in the summer; while spring, autumn, and winter are comparable with those seasons in Ohio.

GENERAL GEOLOGY.

The general geologic features of the district are, briefly: a series of sedimentary rocks intruded by a granite batholith. The contact principally concerned (Fig. 2) is irregularly elliptical in outline with a periphery of about 21 miles, not taking into ac-

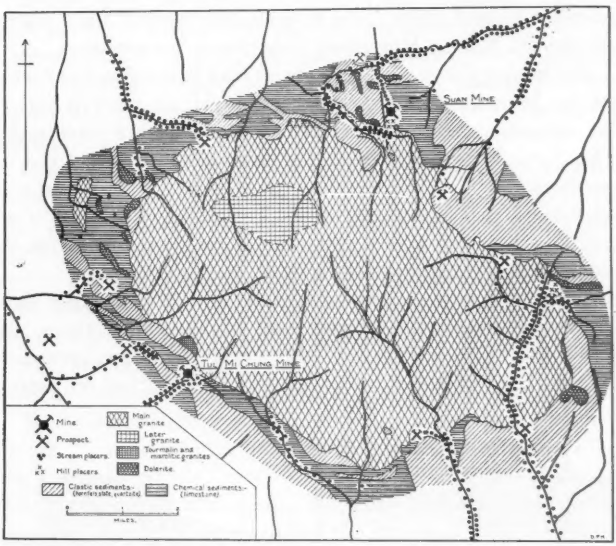


FIG. 2. Suan granite and the Collbran contact. The position of placers, and prospects are indicated.

count the irregularities. The major axis of the ellipse extends in an east-south-east direction. The invasion of the granite has uplifted and pushed aside the overlying and surrounding rocks with tremendous force. Erosion has exposed the mass, showing a rim of the upturned edges of the sedimentary rocks around the granite. In the immediate vicinity of the granite the sediments

have been metamorphosed more or less profoundly into hornfels, schist, marble, and other metamorphic types. In some of these metamorphosed rocks ore deposits containing copper, bismuth, and gold have been found. The granite core forms the highest part of the concession, and hence the drainage is roughly radial from the center of the massif. Streams crossing the contact between the granite and the sedimentary rocks, where gold values are present at the contact, carry the metal downstream across the upturned edges of the sedimentary rocks which form excellent natural riffles. The Koreans have worked these placers for the old Korean Household Department for centuries.

Sedimentary Rocks.—There are at least two sedimentary series on the Suan Concession. If the gneiss of the western part of the concession be of sedimentary origin, there are three series. This Siroo Pong San gneiss (the name being derived from the mountain where it is extensively developed) is the oldest rock on the concession; and over it and complexly folded into it are certain schists and a thin quartzite. These latter rocks are the oldest definitely sedimentary series of the area.

The second series, which detailed study would doubtless show to comprise two series, is composed of limestones, slates, and quartzites. The intricacy of the structure in the immediate neighborhood of the Collbran contact is such that no definite

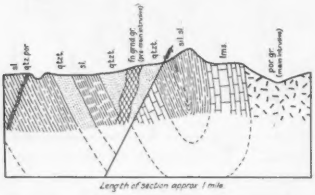


FIG. 3. Showing the contact north of the Tul Mi Chung.

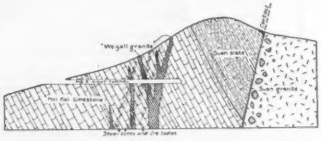


FIG. 4. Diagrammatic section through a part of the Tul Mi Chung mine.

sequence can be decided upon except from general field relations. Fossils are lacking; the batholith cuts across the sediments irregularly (see Fig. 2), and the Hol Kol limestone invariably underlies the Suan slates. This is shown in section in Figs. 3 and 4.

In general the field relations show the Hol Kol limestone to be closer to the batholith than the Suan slates.

Assuming then that the oldest sediments are the nearest to the intrusion, all being upturned about its edges, we have in order from oldest to youngest: Hol Kol limestones, Suan slates, quartzite (with a little conglomerate), Tul Mi Chung limestone, and Tong Am limestone. The Suan mine and the Tul Mi Chung mine are in the Hol Kol limestone. This is the only limestone surficially in contact with the granite. The Hol Kol limestone is in part pure calcite, in part magnesian (but this point needs to be definitely established by analyses), and in no place is it very siliceous or argillaceous, though "blue limestone" is abundant. Near the contact, the limestone is usually a marble, characteristically saccharoidal.

Igneous Rocks.—In order of age the igneous rocks are as follows: the dolerite from its metamorphosed appearance in the field and under the microscope is considered to be older than the main granite intrusion; originally it was a gabbro composed almost entirely of augite, plagioclase at least as calcic as oligoclase, and ilmenite. Almost all of the augite has been altered to hornblende (uralite), and the plagioclase to chlorite, quartz, and other alteration products. The ilmenite has been partially altered to leucoxene.

Near the western part of the contact are certain dikes and stocks. The Tong Am quartz-diorite dikes, closely related to the "Weigall granite" referred to later, are doubtless one of the last phases of the intrusion of the Suan granite. These dikes, strangely enough, have exercised the strongest metamorphic influences observed on the concession. They carried large amounts of mineralizers and metallic sulphides including molybdenite in considerable amount. Molybdenite was not seen elsewhere except in very small amount at Peh Wha.

Certain other granites and diorites of this western part seem to be older than the Suan granite, which is the main intrusive.

Weigall Granite.—The "Weigall granite,"[2] the so-called "sye-

[2] So named after Mr. A. R. Weigall, who first (in 1913) identified the rock as being closely associated with the ores in the lower level of the No. 2 crosscut tunnel at Tul Mi Chung.

nite," occurs in large and small dikes in the workings of the Tul Mi Chung mine (see Fig. 4). There it is without doubt closely connected with the origin of the ores. Microscopic study shows the rock to vary from a quartz monzonite through a quartz diorite to a mica diorite. The average composition is probably that of a quartz-biotite diorite. It is probably an offshoot of the parent magma of the Suan granite intruded shortly after the main mass, but before any great cooling had taken place. Locally through alteration the rock has developed a dirty white or buff color. The biotite was the last of the minerals to succumb to this alteration, and in some places a limey-looking rock with numerous black or brown mica flakes in it marks this stage of the alteration. The alteration has occurred along and out from cracks and small faults in the formation (Fig. 5); and it has

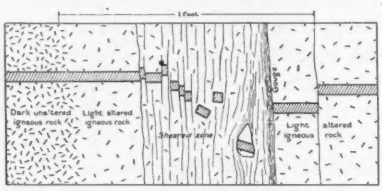


FIG. 5. Vein of calcite in quartz-diorite in the Tul Mi Chung mine.

proceeded so far in many places that the product cannot be recognized as having been derived from the diorite without tracing the intermediate stages. At present the writer can only advance the hypothesis, which seems to be supported by all the evidence available, that the alteration of this igneous rock has been caused by the circulation of hot water through fissures, and presumably given off by the main Suan granite, or possibly, in part, by the "Weigall granite" itself during cooling. These waters were of first importance in the deposition of the Tul Mi Chung ores. In fact, it seems not improbable that a part of the ore has been deposited in a highly altered phase of the diorite.

Suan and Other Granites.—The Hol Kol granite and the Tul Mi Chung quartz-porphyry and tourmaline granite are stocks

which were intruded soon after the main granite. Tourmaline indicates the presence of mineralizers. They are in all probability differentiation products of the parent magma, occurring significantly close to ore deposits. The Chil Sing Dei granite (later granite, Fig. 2) is of the same type as regards origin, but is entirely surrounded by the Suan granite. The possibility must not be overlooked, however, that the Chil Sing Dei granite may have been the primary stock subsequent to the solidification of which the Suan granite may have been intruded. Certain aplite dikes were both precursors and followers of the great intrusion. They do not appear in connection with ores except at Sang Dai, the eastern prospect of the contact (see Fig. 2). The Suan granite itself appears in two principal masses, one being the Unjinsan massif batholith which occupies an area of about thirty square miles; and the other the granite boss of An Ka Roo Kai (Fig. 2) occupying an area of about ¼ square mile. The general shape of the intrusion (Fig. 2) is elliptical, five by eight miles. The long axis extends in a west-north-west, east-south-east direction, which seems to be the general orogenic axial direction of the region. At no place has the writer observed the contact to dip toward the granite, but a local bulge may have caused such a condition to develop in some restricted localities. The average dip of the contact varies from 30° to vertical. About 60° is most common, but great variations occur (see Fig. 6).

The Suan granite is porphyritic in texture, about 5 per cent. being phenocrysts of orthoclase from ¼ inch to 3 inches in size and the remainder a rather coarsely granitoid ground-mass. The phenocrysts are very commonly in the form of Carlsbad twins which in places weather out so as to show the characteristic form of this combination. The phenocrysts are never free from small inclusions of biotite, quartz, and hornblende.

The ground-mass of the Suan granite is made up essentially of plagioclase, orthoclase, quartz, hornblende and biotite. The comparatively large amount of plagioclase and of ferro-magnesian minerals indicate that this is not a true granite, but that it has dioritic affinities. Its true name should be a tonalite-

porphyry; but the term granite has here been used. The plagioclase is oligoclase with an average composition close to $Ab_{82}An_{18}$ as determined microscopically; but the composition varies slightly in different parts of the intrusion. The accessory minerals noted were titanite, apatite, magnetite, and zircon.

About the periphery of the granite, dikes of basalt varying from a few inches to seven feet in width, and from a few hun-

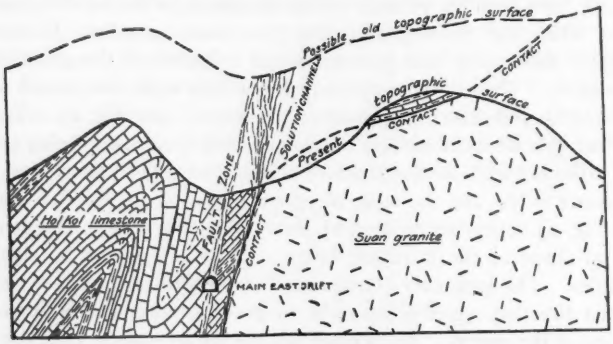


FIG. 6. Diagram showing present and hypothetical former section at the Suan mine. The actual structure is more complicated than shown in figure.

dred feet to half a mile in length, are of frequent occurrence. There is also a small area of basalt of slightly more than an acre in extent in the Morachi Valley southwest of Hol Kol. This basalt is the youngest igneous rock of the contact area. It is doubtless older, however, than the basalt of the lava plains of Korea, one of which lies a number of miles to the southeast of the concession. The basalt cuts both granite and sediments, and seems to have been intruded shortly after the solidification of the granite.

Metamorphic Rocks.—The metamorphic rocks are the granite gneiss of the Siroo Pong San massif with its associated schists and quartzite, all products of regional metamorphism; the hornfels, schist and marble, and garnet-epidote-actinolite, diopside-phlogopite-garnet, diopside-vesuvianite, wollastonite-tremolite

(?), collbranite (a highly ferriferous pyroxene), and similar complicated mineral aggregates, in many places highly metalliferous, were formed by the contact metamorphism of the Suan granite.

Geological Record.

Certain red conglomerates exposed some distance southwest of the concession, along the railway from Pyeng Yang to Seoul, may, because of the lack of fossils, be correlated tentatively with the red Yung Ning sandstone and quartzite of the Liaotung Peninsula, determined by Blackwelder[3] to be of Cambrian (basal) age, and also correlated by him with the Man-t'o (lower Cambrian) of Shantung and Shansi provinces, China. They have been identified by the present writer in Chili province. If this suggested correlation be correct, there can be no doubt that the sedimentary rocks of the Suan Concession are of pre-Cambrian age. They are provisionally classified as follows:

Siroo Pong San granite gneiss .....Archean.
Schist and quartzite of Siroo Pong San region ..Early Proterozoic.
Hol Kol limestone, Suan slates, Tul Mi Chung quartzites, etc. .....Later Proterozoic (possibly Nankow[4]).
Suan granite intrusion with formation of ore-deposits .....Close of Mesozoic.

Paleozoic sediments, now completely removed from the area of the concession, are to be found about Pyeng Yang; hence, it seems certain that these Paleozoic rocks once extended over the area described, but they have been removed by prolonged erosion.

The Siroo Pong San massif seems to be a dome beneath the center of which one may suspect there is another batholith similar to the Suan granite, but not yet exposed by erosion. Carbonated springs and certain zinc and lead veins are suggestive of this hypothesis. No granite similar to the Suan granite is to be seen in Korea in this latitude. The "Korea granite" of von

[3] Willis and Blackwelder, "Research in China," Carnegie Institution of Washington, 1903–4.

[4] *Loc. cit.;* Geology of Shansi Province.

Richthofen, so abundant in Korea, is non-porphyritic, and is chemically different, being more acid than the Suan granite.

ECONOMIC GEOLOGY.

Geologic Relations.—In general the dip of the sedimentary rocks along the Collbran contact is quaquaversal. Near Tul Mi Chung there is an important exception to this rule (Fig. 4). This condition seems to have been developed by the great opposition to the Unjinsan uplift by the Siroo Pong San massif in the western part of the concession, which also was being uplifted probably at the same time. Here the contact is very steep, in some places vertical, and the slate dipping toward the granite has had its edges resorbed by the granite (Fig. 4). Contact metamorphism has profoundly altered some of the rocks bordering the granite. During an early stage of the metamorphism silicates were developed, and at a later stage the sulphides and metallic gold-silver alloy were deposited.

The part which weathering has played in the formation of the ore deposits of the Suan Concession is somewhat problematical. There is very little secondary concentration at the Suan mine. In the western ore-body a small amount of secondary chalcocite was observed. The second period of deposition of chalcopyrite may be due to the action of surface waters. On the other hand, at the Tul Mi Chung mine, secondary concentration is very evident. The lack of secondary concentration at Hol Kol is no doubt largely due to the rapid run-off caused by the steepness of the slopes. Surface leaching penetrated several fathoms, but even stains of malachite do not occur at depths of over 100 feet in the eastern ore-bodies. Chalcocite films were seen at a depth of about 200 feet in the western ore, where topographic and structural conditions are more favorable for the retention of rain-water.

Ore Deposits (Suan Mine).

Form and Structure.—At the Suan mine at Hol Kol there are two distinct types of ore in two distinct groups of ore-bodies, known as the western and the eastern groups respectively. The

western group includes the locally known "western ore-body"; and the eastern group the locally known "central ore-body" and the "eastern ore-body" with its "north split" and "south split."

The ore-bodies of the western group are tabular or lenticular in form and occur on the great fault zone which extends along the west side of the Hol Kol valley (Fig. 7). The ore-bodies of the eastern group are far more irregular, and occur in a series of interlocking fault zones which make up one large zone about parallel to the contact and approximately at right angles to the west fault (Fig. 8). In this zone the last movement was down-

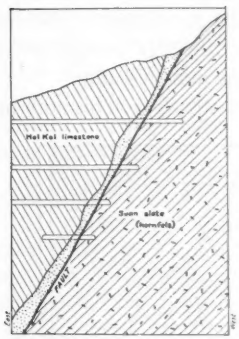


FIG. 7. Diagram of the western group of ore-bodies, showing the mineralized zone at the Suan mine, looking south.

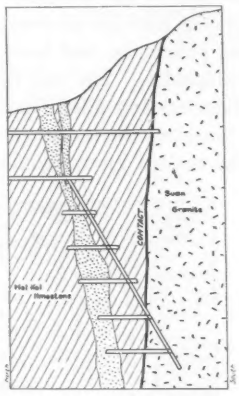


FIG. 8. Diagram of the eastern group of ore-bodies, showing mineralized zone at the Suan mine.

ward about 30° towards the south, and was probably caused by a settling of the granite in cooling. As a whole the zone dips 60°–80° toward the contact in the upper levels, but is about vertical in the lower levels of the mine. The western zone dips 50°–60° to the south, and extends into the granite; while the eastern one runs about parallel to the contact. Distinctive minerals of the western group are tetrahedrite and dolomite, which

occur with the other ore and gangue minerals. Sphalerite and galena may also belong to this category, as they were not certainly recognized in the eastern group. Tetrahedrite and dolomite are never found in the eastern group.

Genesis.—It is clear from both structural and mineralogical evidences that the ores of the two groups have originated differently from the same magma. The ore of the western group was deposited from gold-silver-copper-iron-zinc-lead-antimony-bismuth-magnesium-bearing solutions working up and laterally along the fault zone from the granite into the limestone. The deposits are in the limestone hanging-wall, none having been found in the hornfels foot-wall. Certain silicates, such as diopside and phlogopite, had been developed prior to the deposition of the sulphides. The ores replaced the calcite in preference to these silicates, and filled fractures. Minute veinlets of chalcopyrite constitute the last stage of the mineralization.

In the eastern group, gold-silver-copper-iron-bismuth-bearing

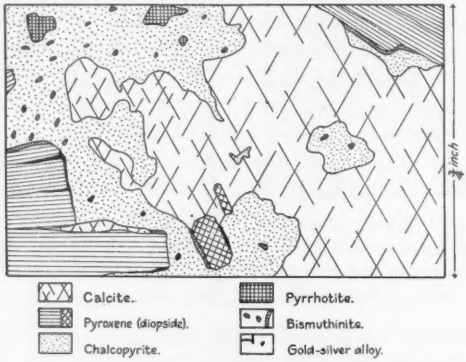


FIG. 9. Drawing to scale from hand specimen, showing selective replacement of calcite rather than diopside by chalcopyrite.

solutions, emanating from the granite, passed upwards along the complicated channels of the fault zone. Calcite was most easily replaced (see Fig. 9), but phlogopite and diopside (see Plate

I., *B*) were also extensively replaced. The solutions altered the wall rock to a much greater extent than in the case of the western group. The presence of pyrrhotite as an important sulphide of the eastern group must also be emphasized.

Paragenesis.—Briefly, the order in which the sulphides and gangue minerals of the second period of mineralization of the two groups of ore-bodies seems to have been as shown in the following table. The observations were made at depths of between 150 and 400 feet below the present land surface.

WESTERN GROUP.

Primary.	*Secondary.*
1. Tetrahedrite.	1. Chalcocite.
2. Tetrahedrite, sphalerite, and galena.	
3. Chalcopyrite, bismuthinite, and gold-silver alloy; bornite.	
4. Dolomite.	
5. 2d chalcopyrite.	
6. Calcite and quartz.	

EASTERN GROUP.

Primary.	*Secondary.*
1. Pyrite.	1. Chalcopyrite.
2. Pyrrhotite, chalcopyrite, and bornite.	
3. Chalcopyrite, bismuthinite, and gold-silver alloy.	
4. Gold-silver alloy and bismuthinite.	
5. 2d chalcopyrite.	
6. Calcite (and a little quartz).	

Overlapping is indicating by repeating the mineral species, so that the metallic content of the depositing solutions is evident for each period. The mineralization proceeded more or less uniformly, and the table does not mean to convey the idea that there was necessarily an abrupt change in the solutions at the tabular divisions. The mineralization of the eastern ore-group of the Suan mine seems to be characteristic of the whole Collbran

contact, with the probable exception of some of the Tul Mi Chung ore, which the writer did not examine in detail. It contains abundant galena and hematite, and has been modified by meteoric waters.

SPECIAL CONSIDERATIONS OF A THEORETICAL NATURE.

Mechanics of the Intrusion.

The method by which so vast a body of rock as the Suan granite could have dispossessed the overlying rocks of their posi-

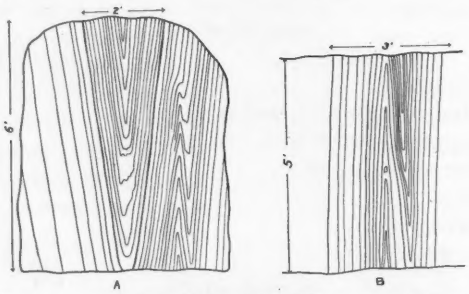


FIG. 10. Sketches to scale from drifts at Peh Wha prospect, Suan concession, at a distance of about 200 feet from the contact.

tion is of great speculative interest. Field observation shows that it was largely by forcing aside the surrounding and overlying rocks. Shortenings actually measured in the field were to ⅓, to ¼, to ⅙, and to 1/10 of the original length of the strata (see Figs. 10 and 11).

If the shortening be assumed to have been the same on each side of the granite, there would be 2½ miles to account for. As a matter of fact, there would be a little more, on account of the turning up of the edges of the country-rock due to the dragging wedge-like action of the inclined sides of the batholith. Assume that there are three miles to be accounted for on each side of the intrusion. Three miles could be accounted for in:

about ⅓ mile for a shortening to 1:10,
about ½ mile for a shortening to 1:6,

about 1 mile for a shortening to 1:3,
about 1½ miles for a shortening to 1:2,

in which the shortening expresses the ratio of final to original lengths. It appears from the actual measurements taken that, even allowing 50 per cent. for such deformation as antedated the intrusion, there is ample room with a shortening of 1:2 to account for the space occupied by the granite in a reasonable dis-

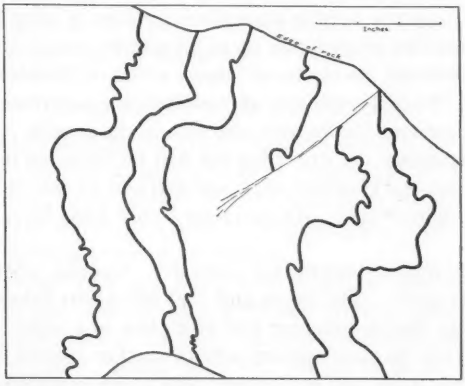


FIG. 11. Reduction from a direct tracing from rock showing the deformation at about 200 feet from the contact with the Suan granite. The crooked lines indicate bedding.

tance on the hypothesis of deformation alone. Allowing 50 per cent. for such ancient deformation, we would assume the very low shortening of 2:3. It would then require six miles to account for three miles shortening. This seems to be a fair average distance, as observed in the field, over which deformation extends from the granite. However, as shown by the above measurements, the greater part of the three miles shortening is easily to be accounted in the first three miles from the contact.

In addition to this evidence favoring deformation of the country as the principle method of advance of the magma, there is most decisive evidence that resorption, or solution of the enclosing rocks took place.

Process of Resorption.

Along the Collbran contact at certain places there is very definite record of resorption having been active at the time of the intrusion of the magma. Fig. 4 illustrates the conditions at the best exposures showing this phenomenon. It was noted in the field that the limestones along the contact showed none of this, but that it was confined to the hornfels and slate areas. It was also noted, however, that in the granite, as far as half a mile from the contact, were in some places patches of pure garnet, in appearance like grossularite, up to an acre in extent; and it may be that these are the results of intense action on limestone blocks, and that silicification most readily explains the occurrences. Unaltered limestone blocks were also seen in the granite.

Unfortunately the writer has not had facilities for the careful microscopic and chemical work necessary to go into this matter of resorption closely. He can record only what he saw in the field.

The hornfels, toward the intrusive, becomes coarser and coarser in grain. The biotite and (or) phlogopite flakes increase in size, but finally disappear and give place to a highly siliceous "augen"; in its place appears a much smaller amount of biotite of different habit, and orthoclase. The augen containing almost invariably small amounts of black tourmaline, euhedral orthoclase and quartz which tend to form with crystal faces seem to have grown into bands and bodies, coalescing until the whole rock took on the general aspect of the granite.

Blocks of the hornfels can be seen in all possible stages from those practically unchanged and plainly showing bedding, to a mass indistinguishable from the granite. In this change there is a pronounced lightening of the color of the substance changed, which seems to be due to a lessening of the ferro-magnesian mineral content and a strong development of quartz and especially orthoclase.

Some of the blocks do not take on the characteristics of the granite, but remain as permanent darker inclusions. Macroscopically and microscopically they have all the characteristics

of an igneous rock, even to containing porphyritic crystals of orthoclase. Without observing their origin, one would call them fragments of some igneous rock taken up by the magma in its journey. Such blocks are infrequent; most of them become part of the magma and indistinguishable from it. Veinlets of quartz and orthoclase penetrated the hornfels in some places, forming an intricate network. In such places the rock between the veinlets, in a distance of six inches to two feet, has become highly feldspathic, gradually taking on the aspect of the granite. An interesting point is the apparent disappearance of ferro-magnesian mineral matter and the appearance of feldspars.

Detail History of the Mineralization.

Under this heading the writer confines himself to the mineralization of the Suan mine, where more complete observations and more careful study of thin sections have been made than elsewhere. The conclusions derived from the Suan mine, however, apply to the remainder of the contact.

The country rock is a fairly pure limestone, possibly in part magnesian and siliceous, of fine-grained original texture. Contact metamorphism of the pure limestone produced a marble with the grains some 125,000 times the size of those of the original limestone. Intense deformation caused the grains of the marble to bend or flow.

In many places along the contact, notably at the Suan mine, extensive silicification of the limestone occurred during the period of static metamorphism. The actual occurrence shows that large quantities of silicates occur in such relations as to suggest very strongly that silica, alumina, and iron have been introduced from an outside source. In particular, there is a mass of many hundreds of tons of almost solid phlogopite in connection with the "central ore-body." To the writer it is unreasonable to assume such enormous quantities of phlogopite, a mineral of the approximate constitution[5] SiO_2—40 per cent., Al_2O_3

[5] Dana's "Textbook of Mineralogy," phlogopite. Analysis of the material from the mine would make the elucidation of this problem more certain, especially as regards the fluorine content of the phlogopite.

— 15 per cent., MgO — 27 per cent., K_2O — 9 per cent., H_2O — 4 per cent., F — say 1 per cent., to have been formed in a limestone of whatever constitution without the accession of chemical substances from outside sources. While silica and alumina, as well as magnesia, might be derived from the limestone, the first two being concentrated by the removal of carbonate to suit the required composition of the phlogopite, it seems improbable to expect potassia and fluorine to follow the same rule. In the case under observation, situated on and near a trunk zone of mineralization (and later metallization), it seems much more reasonable to assume that practically all of the calcium carbonate was removed and replaced by phlogopite.

In another part of the mine, Level No. 4, East, may be seen prismatic crystals of phlogopite, up to 1 cm. in diameter, which have replaced calcite. Here is definite proof that the silicate may replace the carbonate. It may be asked: Where did the silica, magnesia, alumina, potassia, water, and fluorine come from? The two are associated with an undetermined brown mineral, possibly ankerite, and a little chalcopyrite of later age.

Again, a large part of the eastern ore has as its principal gangue, diopside. It occurs in great quantity, in small and large (Plate III., *A*) radial aggregates, in some places penetrating calcite (see Plate II., *A*), and in many places composing by far the major part, certainly 90 per cent. of the rock. While it is conceivable that certain constituents might have been driven off from the original rock in such a way as to leave silica, lime, and magnesia in the exact proportions to form diopside, it could not have been so done without a lessening of the volume of the rock. There is no evidence of such shrinkage. In fact, the evidence is most decisive that the diopside was formed in a perfectly quiet rock. Radial diopside crystals extended into calcite of large crystallographic dimensions (now replaced in many places by chalcopyrite), and the writer has numerous slides showing the same uniform growth in smaller individuals. Fig. 9, Plates IV., *A* and *B*, also show diopside crystals well developed, and broken after their growth had ceased. It is necessary to con-

clude, then, for those large masses of almost pure diopside, that either the composition of the original rock was close to that of diopside, or, since all evidence indicates that the original rock was a limestone, carbon dioxide has been removed together with alkali earth oxide, and that silica has been brought in in such proportions as to form the stable diopside.

Similarly, deformation of the phlogopite, individuals not uncommonly being two inches across, was entirely after its formation. The mineral was formed under quiescent conditions, and there is no evidence of change of volume of the rock during the formation of the mineral.

There occurs very commonly in the marble walls of the orebodies of the mine, and in massive form in the western group, a black acicular mineral in characteristic stellar aggregates (see Plate III., *B*). This mineral has been referred to by Koto[7] as ilvaite. In the unfortunate lack of a chemical analysis the identification of this mineral is doubtful. The writer believes, however, from microscopic evidence, and from that of mineral association, that the mineral it not ilvaite, but a highly ferriferous pyroxene of the hedenbergite type. There is a definite possibility that this mineral may be very close to the iron end of the isomorphous $(Ca, Fe)(SiO_3)_2$ series; if not indeed the terminal pyroxene, ferrous metasilicate, $FeSiO_3$. He therefore proposes the name "collbranite," after Mr. H. Collbran and his son, Mr. A. H. Collbran, who have made the Suan mine a producer. This mineral will hereinafter be referred to as "collbranite" (Plate III., *B*). The occurrence of collbranite corroborates in all particulars the history of the diopside and phlogopite.

The garnet was also formed before the general disturbance which preceded the advent of the sulfid-bearing solutions.

Thus there is established the following major events in the history of the genesis of the ores of the Suan mine: (1) A period of great deformation of the original country rock; (2) a prolonged period of quiescence, during which recrystallization and the development of large amounts of metamorphic minerals took

[7] B. Koto, *Journal of the College of Science*, Imperial University, Tokyo, May, 1910.

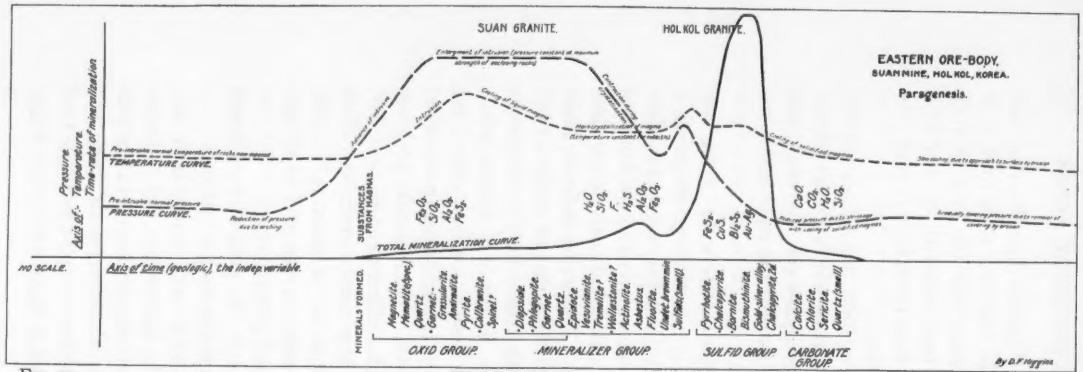


FIG. 12.

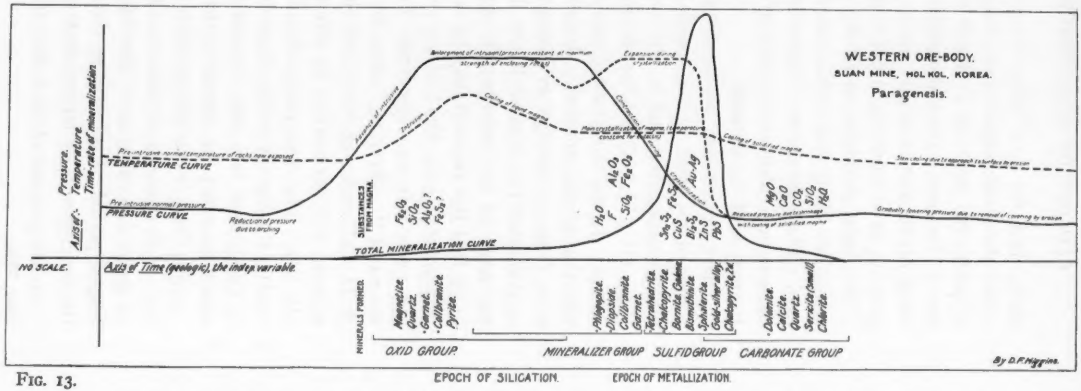


FIG. 13.

Diagrams of pressure temperature and rate of mineralization changes covering the geologic episode of the intrusion of the Suan granite, as now recorded in the western and eastern group of ore-bodies of the Suan mine.

place, with the accession of water, silica, fluorine, alumina, some sulphur, and probably some iron; (3) initiation of stresses impressed from without the country rock, and under pressure greater than that required for flow in calcite and less than that required for flow of diopside; (4) immediately following the deformation the circulation of ore-bearing solutions.

In Figs. 12 and 13 are brought together these facts with some others in a diagrammatic form, showing their probable and hypothetical relations to the heat, pressure, and rate of metallization induced by the Suan granite, for the ore-bodies. Pressure, temperature, and time-rate of mineralization (not amount of mineralization) are plotted as against time. Present data are insufficient to assign definite scales to the curves, but it is believed that they show the correct relations of events. The irregularities of the curves represent an incident in geologic time, in which the normally nearly horizontal curves of pressure and temperature, together with the normally zero curve of total mineralization are greatly disturbed by the advent of the Suan granite intrusion. A curve of recrystallization might have been added, which would have had a maximum at about the time of the maximum temperature.

By recrystallization is meant in this paper those readjustments of crystalline shape and (or) composition taking place in a rock without accessions of foreign material, other than that of catalyzers or solvents, which leave essentially unchanged the original chemical constitution of the rock, but material may be removed from the rock. By mineralization is meant in this paper those changes in the chemical constitution of a rock which involve accessions to the original material (in absolute quantity) of the rock. It is with the changes of mineralization thus defined that the curves figured in Figs. 12 and 13 deal.

Examination along the Collbran contact has shown that the mineralization falls naturally into two epochs and four groups, somewhat overlapping especially in the case of the first and second. This grouping is based on the time of appearance of the minerals and consequently their association. The grouping is

EPOCH OF SILICATION EPOCH OF METALLIZATION

FIG. 13.

Diagrams of pressure temperature and rate of mineralization changes covering the geologic episode of the intrusion of the Suan granite, as now recordedin the western and eastern group of ore-bodies of the Suan mine.

therefore a fundamental one in the paragenesis of the minerals. With each group more or less characteristic substances seem to have been received from outside sources—the magma. According to these substances the groups have been named.

For the western group at the Suan mine the paragenesis of the minerals is as follows:

Epoch.	Group.	Mineral formed.	Substances received from the magma, or by its direct influence.
Silication.	Oxide group.	Magnetite.	Fe_2O_3.
		Quartz.	SiO_2.
		Garnet (X).	Al_2O_3.
		Collbranite (X).	FeS_2
		Pyrite.	
	Mineralizer group.	Phlogopite (X).	H_2O.
		Diopside (X).	F.
		Collbranite.	SiO_2.
		Garnet.	Al_2O_3.
		(In many other places along the contact, vesuvianite is a prominent mineral here.)	Fe_2O_3.
Metallization.	Sulfide group.	Tetrahedrite (X).	CuS.
		Chalcopyrite (X).	Sn_2S_3.
		Bornite.	FeS_2 (or Fe_2S_3).
		Sphalerite.	ZnS.
		Bismuthinite.	Bi_2S_3.
		Galena.	PbS.
		Gold-silver alloy.	Au-Ag.
		Chalcopyrite 2d.	
	Carbonate group.	Dolomite (X).	MgO.
		Calcite.	CaO.
		Quartz.	CO_2.
		Sericite (in small amount).	SiO_2.
		Chlorite.	H_2O.

(X) Indicates the minerals most abundant.

The origin of the magnesia and the potassia of the phlogopite is not referred to in the above table pending chemical analyses of the phlogopite.

Starting with the definitely established fact that the second group was formed during a period of quiescence, we may reason as follows, the diagram in Fig. 12 being based on this reasoning:

The first indication of the approach of the magma in the region of the present ore-deposit was probably a slight reduction

of pressure[8] due to the arching of the rocks overlying the rising mass. This is shown in the diagram by a downward bend of the pressure curve which had been approximately horizontal for an indefinite period of time. It is assumed that the pressure of the overburden was not equal to that of the maximum strength of the rocks at this horizon. At that time the temperature, likewise approximately constant for an indefinite time, had not risen.

When the forerunners of the magma appeared and the active pressing apart of the sediments began, the pressure rose rather promptly to the maximum possible, that of the maximum strength or resisting power of the sediments. That the pressure persisted at this constant throughout most of the time of the enlargement of the intrusion is shown by the great amount of flowage of the surrounding rocks. The temperature, lagging a little on account of the time necessary for conduction, rose rather promptly to a maximum, but began to fall as soon as that part of the magma near the wall of the batholithic cavity became approximately stationary, that is, when the accession of heat from the magma became less than the amount of heat conducted away by the surrounding rocks. The temperature after having fallen from the maximum became a constant value determined by the crystallizing or freezing temperature of the eutectic. If we assume that there was a considerable amount of latent heat of crystallization the temperature probably then for some little time held a constant value lower than the maximum; during which time the pressure fell if there was contraction during crystallization or remained about constant if there was expansion during crystallization. It is probable that reduction of temperature of solid parts about offset the expansion due to crystallization.

Study of the contact zone shows that there was introduction of the oxide group during the time of the intrusion, and during part of the time of quiescence. But the appearance of the mineralizer group, though beginning before quiescence, attained its greatest development in the period of quiet crystallization of the magma. This part of the episode of intrusion was probably as

[8] For a discussion of the probable pressure, see under the next section.

long as all the other parts except the final cooling of the solidified mass put together. In the diagram it is probably not extended long enough. Water, fluorine, silica, alumina, were all given off by the magma in great abundance, and caught by the lime and magnesia of the limestone. It is not improbable that iron, magnesia, and potassium were also given off in the same way. The fault zone of the two groups of ore-bodies (see Figs. 6, 7 and 8) formed a channel of escape for these solutions.

At the close of the epoch of crystallization in the country rock the metal-bearing solutions appeared. They must have come at the close of the crystallization of the magma, if we may carry further the reasoning that the main part of the silicate mineralization was during the crystallization of the magma; for there is no evidence that further mineralization of the mineralizer type (production of silicates) took place after the metallization, or even during it. There seems to have been a very sharp break in the paragenesis at this point.

The cessation of silicification and the beginning of metallization was marked also by readjustments of the rocks. This part of the history is not as well marked in the western group as in the eastern one, for reasons which will be explained in the discussion of the eastern group. This readjustment is interpreted for the western group as having been due to the shrinkage of the batholith, or its solid portions, after solidification.

At that time the sulphide-bearing solutions appeared from sources lower than the present deposits, but certainly in the magma, for the western group deposits extend along the fault for some distance into the granite itself, first attacking the calcite, then phlogopite and diopside, replaced in part the rock along and near the fault zone (see Fig. 7), and filled fissures and crevices as these opened.

The order in detail of the deposition of the sulphides and metals seems to have been:

(1) Tetrahedrite.
(2) Tetrahedrite, sphalerite, and galena.
(3) Chalcopyrite, bornite, and bismuthinite.

(4) Gold-silver alloy (89 per cent. Au).
(5) Chalcopyrite 2d, cutting across the others.

The current theory that quartz, solidifying last from the magma from silicic acid, causes the liberation of large quantities of water, free to gather and take away metals in a sort of "mother liquor," seems to be strikingly corroborated here.

Following the deposition of the sulphide group, dolomite, calcite, and quartz were deposited in veins and cementing breccias caused by more movement in the fault zone, presumably by the contraction of the cooling solid granite. Minor amounts of sericite and considerable chlorite were developed by the alteration of older minerals, but dolomite is far larger in quantity than all the others together. Whether the dolomite represents a true magmatic product, or whether it was selectively deposited by hot waters of whatever origin after having been dissolved from the surrounding limestone can not be settled without further study; but the writer believes that the magnesia and the carbon dioxide were in large part at least derived from the magma along with quartz in the last stages of its cooling. A little chalcopyrite followed part of the dolomite.

In conclusion for the western group, the time-rate of the mineralization was very slow in the early stages of the intrusion, increased slowly during the crystallization of the magma (but in this period there was the greatest *quantity* of mineralization), rose to a sharp and pronounced maximum at the close of the crystallization of the magma, and was followed by a rather rapid falling off to zero (or nearly so) after the magma had become solid.

With the eastern group the series of events was somewhat different (Fig. 12), and it is thought that the eastern-type is more general for the larger profitable deposits. It is almost certainly the type for the Tul Mi Chung mine. A normal, undisturbed condition is shown in Fig. 12, diagramming pressure, temperature, and rate of mineralization of the western group, but, although in general outline the same, the curves in Fig. 13 suffer change on account of the intrusion of a second granite, a small stock close to the ore-deposits, the Hol Kol granite.

The pronounced deformation closed the period of quiet silication in which grew diopside and phlogopite in great abundance, and is interpreted as having been caused by the intrusion of this stock of the Hol Kol granite, which field relations show clearly to be later than the Suan granite. The Hol Kol granite, from microscopic observations, seems to be somewhat more acid than the Suan granite, is of finer grain, and contains many miarolitic cavities lined with orthoclase and quartz crystals. This is interpreted as indicating the presence of abundant mineralizers, which is in accord with the development of fluorite and abundant asbestos (replacing calcite usually), and amphibole, this latter usually in positions crystallographically parallel to the older diopside (see Plate II., *A*). Plates IV., *A* and *B* show typical examples of diopside crystals, broken after large growth, about which chalcopyrite, bismuthinite, and metallic gold-silver alloy were deposited after the deformation of the crystals. Plate II., *B* shows chalcopyrite and bornite replacing diopside and phlogopite in the eastern ore of the Suan mine, thus again demonstrating the later age of the sulphides.

The sequence of events, referred to in Fig. 13, is as follows: (1) a slight lessening of pressure due to arching over the approaching magma; (2) a sharp rise in pressure to the maximum possible for the enclosing rocks; that is, till they readily flowed, closely followed by a rapid rise in temperature; (3) constant pressure during the enlargement of the magmatic cavity and part of the period of crystallization (on the assumption that there was no great increase of volume of the igneous rock during crystallization), accompanied by a gradual fall of temperature till one was reached in accord with the temperature of freezing of the eutectic established. This period (probably not shown long enough in the diagram in comparison with the rest of the figure) was the period of silication, marked at first by the appearance of magnetite, specular hematite, quartz (these three not in large amount, however), pyrite, both iron and calcium garnet (the latter predominating), collbranite,[9] and possibly spinel. Later

[9] See an earlier part of this paper for definition of the species collbranite.

came the more important silication, represented particularly by large quantities of diopside and phlogopite. Garnet, epidote, quartz, asbestos, wollastonite (?), and an undetermined brown mineral were not unimportant. Fluorite, actinolite and vesuvianite (these two are especially prominent at the prospects Sang Dai, for actinolite, and Peh Wha, for vesuvianite), tremolite (?), and minor amounts of the sulfides. (4) Next appeared the Hol Kol granite, raising the pressure and temperature. The readjustments necessary for the acccommodation of this stock are recorded, as explained above. Quickly following the advent of the Hol Kol granite came (5), the period of intense mineralization—this time metallization instead of silication. The order of the sulphides was as follows:

1. Pyrite, in small amount.
2. Pyrrhotite, chalcopyrite, and bornite. The order in these three cannot be certain without metallographic work, but pyrrhotite seems to have been the first and chalcopyrite seems to have begun before the bornite.
3. Chalcopyrite, bismuthinite, gold-silver alloy; probably also overlapping bornite.
4. Bismuthinite and gold-silver alloy.
5. Second chalcopyrite.

Under 2 and 3 the greatest quantity of mineralization took place. Chalcopyrite and bornite[10] are *par excellence* the sulphides of the eastern group. The second chalcopyrite is small in amount, cutting earlier sulphides and the first chalcopyrite in tiny stringers. (6) Calcite, quartz, chlorite, asbestos, and sericite appeared as additions or as alterations under the influence of magmatic water of reduced metal and sulphur content. (7) The deposition of calcite and a little quartz is going on to-day in scattered open cavities. For calcite the scalenohedron form ("dog-tooth spar") favors the upper levels of the mine; but the flat e-rhombohedron favors the lower levels, and hence is probably

[10] Under the microscope a border of slightly darker bornite was noted around larger and older masses of the same mineral. The occurrence is not understood but possibly may represent a compound of the chalcopyrite-chalcocite series.

more stable at higher pressures than the spar. These occurrences seem to be distinctly post-intrusive.

In conclusion for the eastern group, it may be said that the time-rate of the mineralization was very slow in the early stages of the intrusion. It increased slowly during the crystallization of the magma (during which time, however, was the greatest absolute amount of mineralization—silication), but was suddenly interrupted with the advent of the Hol Kol granite stock. With the cooling of this stock and the further cooling of the main Suan granite batholith, the time-rate turned to a strong maximum, during which period the metallic sulphides and metallic gold and silver were introduced. This was followed by a rapid falling off of the rate of mineralization to zero (or nearly so) after the magma became solid.

LIST AND CLASSIFICATION OF MINERALS OBSERVED.

The chart on page 29 is a complete list and classification of the minerals observed in the metamorphosed country rock along the Collbran contact.

SUMMARY.

A region of pre-Cambrian slates, limestones, and quartzite, together with earlier igneous rocks, has been intruded by a batholith of porphyritic granite (tonalite) approximately roughly elliptical in shape and occupying an area, as now exposed, of some 30 square miles. Strong contact metamorphism of the rocks close to the granite took place, involving recrystallization of minerals *in situ* and mineralization with accession of material from the magma. During an early stage in the development of the contact metamorphism notable additions of silica, alumina, ferric oxide, potassia (?), fluorine, boron, and to a lesser extent metallic sulphides took place; mineralization probably being assisted greatly by the solvent and catalyzing action of water, fluorine, and boron. Following this early stage of silication certain crustal disturbances, caused both by the injection of subsidiary stocks and dikes from the magma which in part had already solidified and also by readjustments in the magma itself.

- **Epoch of Metallization.**
  - Sulphide Group.
    1. Pyrite (in cubes).
    2. Pyrrhotite.
    3. Chalcopyrite.
    4. Bornite.
    5. Tetrahedrite.
    6. Bismuthinite.
    7. Sphalerite.
    8. Galena.
    9. Molybdenite.
    10. Undet. gray mineral (sulphide?).
    11. Hematite, blue.
    12. Gold-silver alloy.
  - Carbonate Group.
    1. Calcite.
    2. Dolomite.
    3. Siderite.
    4. Ankerite (?) (probably formed here).
    5. Quartz.
    6. Sericite.
    7. Chlorite.
- **Epoch of Deep-seated Hydration. (Hydroxyl Group.)**
  1. Quartz.
  2. Chalcedony.
  3. Chlorite.
  4. Epidote.
  5. Sericite.
  6. Serpentine.
  7. Asbestos.[11]
  8. "Mountain leather."
  9. Zeolites.
  10. Amphibole (here or under mineralizer group, q.v.).[12]
- **Epoch of Weathering.**
  - Deeper Group.
    1. Chalcopyrite.
    2. "Copper-pitch."
    3. Chalcocite.
    4. Undet. white sulfide.
    5. Calcite.
    6. Quartz.
  - Surficial Group.
    1. Cuprite.
    2. Metallic copper.
    3. Azurite.
    4. Malachite.
    5. A manganese oxide (?).
    6. Undet. yellow mineral.
    7. Limonite (from pyrite).

[11] There are in all probability two minerals covered by the term asbestos; but clearly some asbestic mineral was formed both in the epoch of silication and in the epoch of deep-seated hydration.

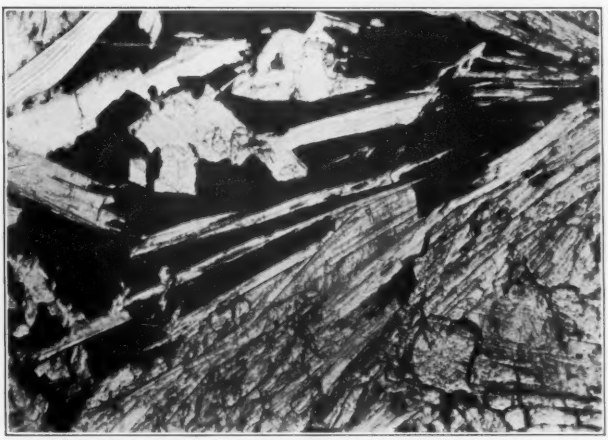
[12] The time of the origin of the amphibole (see Plate II., *A*) is uncertain. The writer inclines to the opinion that it was formed in the last part of the epoch of silication.

EXPLANATION TO PLATE I.

FIG. A. General view of Camp at Hol Kol, Korea, looking north down the valley towards Suktari.

FIG. B. Chalcopyrite (black) replacing phlogophite and diopside, Suan Mine.

A.



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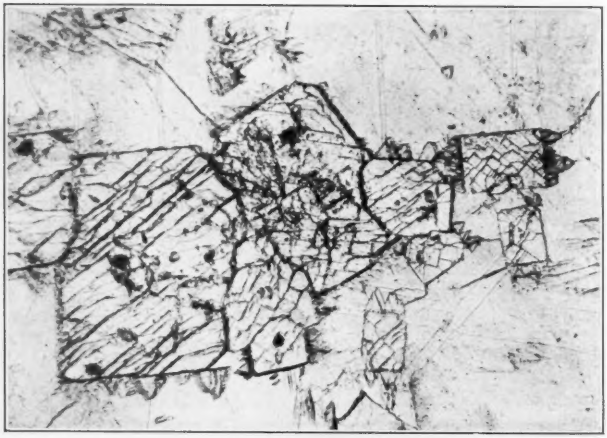

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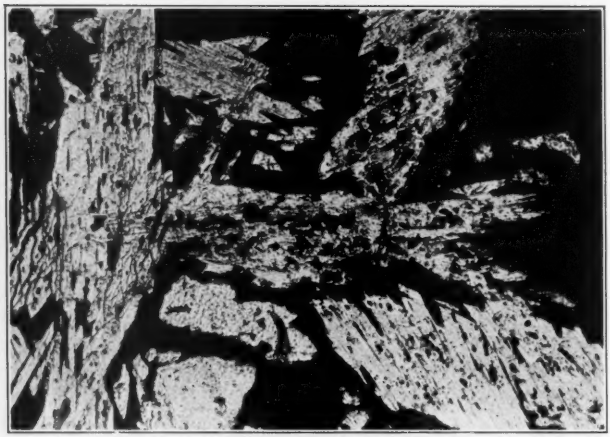


B.

EXPLANATION TO PLATE II.

FIG. A. Cross-section of pyroxene (diopside) aggregate piercing calcite. The forms (100), (010), and (110) are shown. Note the crystallographically parallel amphibole in several places developed later than the pyroxene. Section about parallel to c. ×70.

FIG. B. Chalcopyrite and bornite (black) replacing diopside. Note intricacy of contacts. There is no sign of change of volume. Suan Mine.

EXPLANATION TO PLATE III.

FIG. A. Characteristic radial aggregate of coarse diopside crystals from Eastern ore-body of the Suan Mine. × 1½.

FIG. B. Highly ferrugenous pyroxene in marble from the Suan Mine, described as collbranite.

A.

B.

A.

B.

EXPLANATION TO PLATE IV.

FIG. A. Fragment of diopside crystal from the eastern ore-body of the Suan Mine showing later crushing and splitting along cleavage planes parallel to the basal pinacoid. Later, chalcopyrite (light gray), bismuthinite (white spots), and metallic gold-silver alloy (too small to show) were deposited in crevices and along sides of the crystal. This specimen illustrates two stages of mineralization: (1) growth of large crystals under static conditions, followed by deformation, and (2) the introduction of metal-bearing solutions. $\times 3$.

FIG. B. Crystal of diopside showing static metamorphism, with possible introduction of silica and iron-bearing solutions, followed by deformation and metallic mineralization. $\times 3$.

A short period of intense mineralization followed these crustal disturbances which had caused fracturing and deformation. At this time metallic sulphides and the gold and silver alloy were deposited, the latter occurring in sufficient quantity to make the average value of the ore about ten dollars a short ton. Along different parts of the contact different metals appear in different relative proportions, but copper, bismuth, and gold are always present. Subsequently erosion has exposed the deposits; but secondary concentration has by no means been equally developed in all places. The depth at which the deposits were formed was probably about 20,000 feet, at a pressure of about 1,500 atmospheres to the square inch; but this estimate may be subject to great revision.

SOME FEATURES OF MAGNETIC SURVEYS OF THE MAGNETITE DEPOSITS OF THE DULUTH GABBRO.

T. M. Broderick.

INTRODUCTION.

This paper outlines the methods used and some of the results obtained in making a magnetic survey of the magnetite deposits of the Duluth gabbro. Certain unusual features of the magnetic fields encountered are described and explanations for them suggested. The field work was carried on by F. F. Grout and the writer for the Minnesota Geological and Natural History Survey in preparation for a bulletin on the titaniferous magnetites of northeastern Minnesota.

The magnetite deposits in the gabbro area are of two distinct modes of origin. Some of them are clearly segregations of the gabbro, while others are metamorphosed inclusions of the sedimentary Gunflint iron-bearing formation. The segregations of the gabbro consist essentially of magnetite and plagioclase feldspar and they occur as bands which grade into the normal phases of the banded gabbro by decrease in the amount of magnetite. The highly metamorphosed inclusions of sedimentary iron formation are in many cases banded, but the bodies occupy haphazard positions with respect to gabbro structures. The chief minerals of the inclusions are magnetite, quartz, fayalite, amphibole, and pyroxenes. Plagioclase feldspar, so characteristic of the segregations of the gabbro, is almost entirely lacking in the inclusions. Titanium in the mineral element occurs in variable amounts in the deposits of both classes. As will be shown, the magnetic fields produced by these two types of deposits are very different.

METHODS AND GENERAL RESULTS.

Introduction.—Magnetic work on the gabbro was carried out with certain modifications, according to the usual methods em-

ployed in the Lake Superior region. The instruments used were the dip and dial compasses. Hotchkiss has described the uses, mechanism and other features of these instruments.[1] Two types of magnetic traverse were made, (1) those in the nature of general reconnaissance, and (2) mapping a magnetic area in detail.

Reconnaissance Methods and Results.—The usual method of magnetic reconnaissance work on a large area is to make traverses, generally on north-south section and quarter section lines, reading the instruments every hundred paces. By connecting places of abnormal attraction, from one traverse line to another, magnetic belts or lines are obtained, which usually give the strike of a magnetic rock, in some cases an iron formation. Later, more detailed magnetic work and drilling may result in the discovery of ore bodies in an area even where there are no outcrops. There are numerous features which made this type of reconnaissance work of almost no value in the work in the Duluth gabbro. In the first place, prospectors have already reported practically all the outcrops which have the least appearance of being high in iron. They were naturally on the lookout for ore because of the proximity of the Vermilion and Mesabi ranges. The region has many outcrops and very thin drift, so that the information gathered from these sources, together with the many published references to ore outcrops, is likely to be fairly complete, and the chances of locating new deposits by magnetic traverses correspondingly poor. Most of the magnetic bodies are long and narrow, extending east and west. Their influence upon the dial compass is therefore almost nil. Since the ore outcrops at the surface the dip needle is not affected a short distance away, so that a north-south traverse with readings at one hundred pace intervals would be very likely to miss a strip of ore. Many of the ore bodies are only a few hundred paces in length, greatly reducing the chances of finding them by magnetic traverses one half mile or one mile apart. Many of the inclusions are extremely variable in their composition, therefore variable in their disturbing influence upon the earth's field. On some of the iron

[1] Hotchkiss, W. O., "Mineral Lands in Part of Northwestern Wisconsin," Wis. Geol. and Nat. Hist. Survey Bull. 44, pp. 75–133.

ranges, magnetic lines are traced by dip needle variations of one half degree. On the Duluth gabbro, the readings over the normal country rock vary as much as twenty degrees. Finally, it was found that magnetic readings upon some of the largest magnetite deposits showed no more variation than could be obtained over the normal gabbro. All these factors should tend to discourage attempts to search for new bodies of ore in the gabbro by the reconnaissance method here discussed.

Detailed Methods and Results.—Detailed or close magnetic surveying, starting from an outcrop of magnetite, is to be recommended for approximately mapping the ore body. It consists in taking closely spaced readings. In much of the work the dip needle was read at the corners of 12½-foot squares, and the dial compass on 25-foot squares. For practical purposes readings on 50-foot squares should be sufficient. By this method apparently unrelated ore outcrops one half mile apart were found to be on the same band of magnetite gabbro. On the other hand, ore bodies apparently connected were found to be disconnected. There was an area several miles in length where there were so many outcrops of ore that it seemed fairly certain that they formed a continuous band. Detailed magnetic work, while it served to extend most of the patches of ore beyond the outcrops, shows conclusively that the area, instead of being underlain by a continuous band of ore, is underlain by gabbro in which there are short bands of ore. Thus, in some cases, the magnetic observations served to increase the apparent value of a prospect, in others to decrease it.

After obtaining a clear conception of the various types of ore, one finds that it would be a simple matter to determine much concerning the type of ore by the magnetic properties of the deposits, even though there might be no outcrops. The banded gabbro ores give a magnetic belt which runs parallel to the strike of the banding of the gabbro. In some cases the magnetic belt is entirely negative, that is, it causes the north end of the needle to be repelled. This type of ore shows a minimum of the erratic effect due to local polarity. Fig. 14 shows a portion of one of

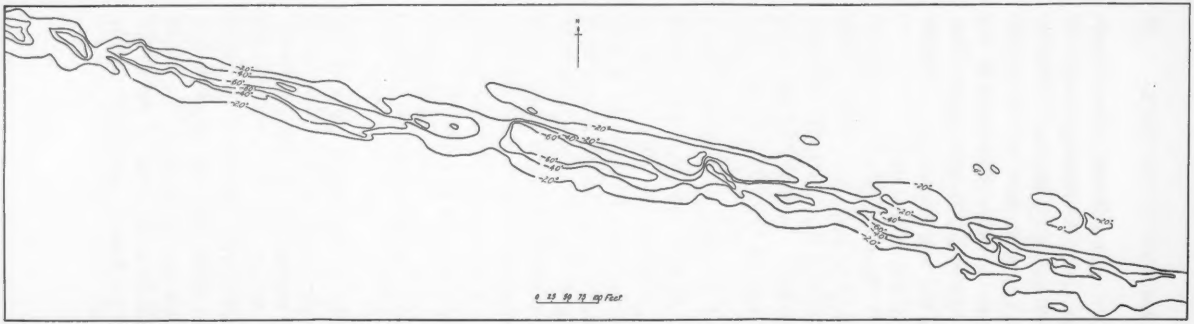


FIG. 14. Contour map of dip needle deflections over a narrow segregation band of magnetic ore in the Duluth gabbro. All deflections negative, contour interval 20°.

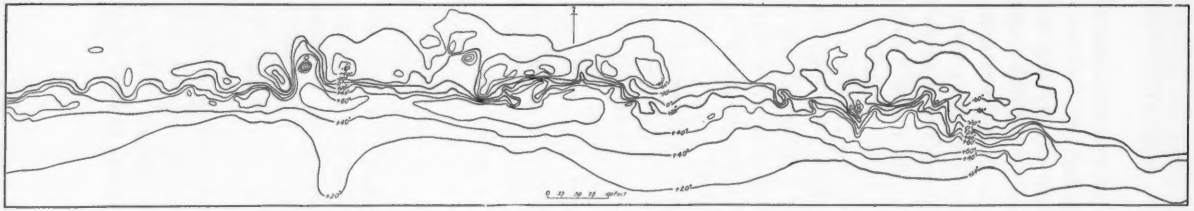


FIG. 15. Contour map of dip needle deflections over a highly metamorphosed inclusion of sedimentary iron formation in the Duluth gabbro, a belt of negative deflections north of a belt of positive deflections. Contour interval 20°.

these belts with the dip needle readings mapped as contours. Such a map closely corresponds to the "maps of vertical intensity" issued by the Canadian Department of Mines. Contrasted

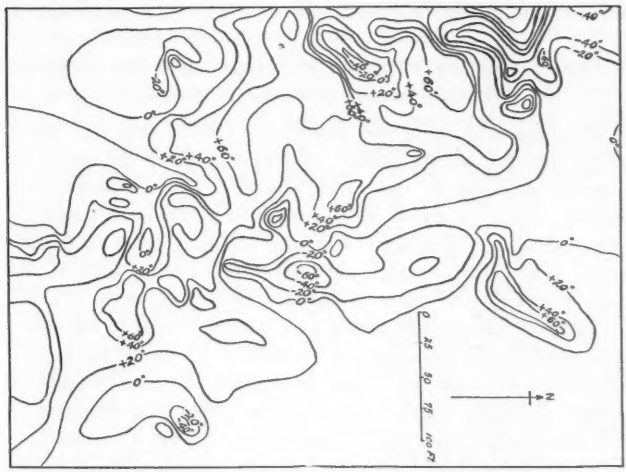


FIG. 16. Contour map of dip needle deflections over a highly metamrophosed inclusion of sedimentary iron formation in the Duluth gabbro. Distribution of negative and positive deflections very erratic. Contour interval 20°.

with the magnetic fields of the gabbro bands are those of the inclusions. Fig. 16 is a contour map of the dip readings over a part of an inclusion. There are high positive and negative dips within a few feet of each other. The magnetic disturbance caused by the whole inclusion is not strong enough to offset the local effects of the irregular distribution of the magnetite near the surface. Still a third type of magnetic field is shown by Fig. 15. This bears some resemblance to the diagram of the dip variations of the gabbro bands, in that the contours run in an east-west direction, and they show considerable regularity. However, there are several points which serve to differentiate this magnetic field from that of a band in the gabbro. The general direction of the contours, instead of running parallel to the

a belt of negative deflections north of a belt of positive deflections. Contour interval 20°.

banding in the gabbro, cuts across it. The field is divided in two parts, being negative to the north and positive to the south. The deposit is probably an intensely metamorphosed inclusion of a sedimentary iron-bearing formation.

INTERPRETATION OF PECULIAR TYPES OF MAGNETIC OBSERVATIONS, PARTICULARLY NEGATIVE DIPS.

Introduction.—There are interesting results obtained which have a bearing on the theory of magnetic fields produced by magnetic deposits in the earth. Smyth[2] has mathematically worked out the nature of the disturbances of the earth's field by iron ore bodies. Hotchkiss[3] has done the same from an experimental side. The complex conditions in the field, such as the great irregularity of some of the structures, the depth of drift, the irregular topography, the lack of information as to the structural relations of the magnetic formation, all make the proper correlation of cause and effect in magnetic fields a matter of extreme difficulty. The disadvantageous effect of a thickness of drift over the bed rock may be realized by drawing a new surface line about half an inch above the ones shown in Figs. 17–19. The general effect would be to lessen the field intensity (roughly indicated by the degree of crowding of the lines), decrease the amount of variation of the dip needle, and to widen the zone of abnormal readings. The efforts of Hotchkiss and Smyth have been to arrive at certain conclusions as to proper interpretation of certain types of disturbed magnetic fields, in terms of structure, size, depth of burial, and other unknown conditions of the formation causing the disturbance. Their results are all based on the assumption that the nature of the disturbance of the earth's field by a magnetic body is conditioned chiefly by the magnetism induced in the body, since it attained its present structural attitude in the earth's crust.

One of the most common and perplexing questions of magnetic observations is the meaning of negative dip needle deflec-

[2] Smyth, H. L., U. S. Geol. Survey Mon. 36, Chap. 2, Pt. II.

[3] Hotchkiss, W. O., "Mineral Lands in Part of Northwestern Wisconsin," Wis. Geol. and Nat. Hist. Survey Bull. 44, pp. 75–136.

tions. The term "negative" is used in the discussion to describe those deflections of the dip needle in which the south end is depressed or attracted. This is the general usage of the term among those who work with the dip needle in the Lake Superior region. Hotchkiss[4] makes it clear that there are two causes which will give negative readings, a lowering of the intensity of the field, or a flattening of the inclination of the field. He states that negative readings are due almost entirely to the former cause. There are several types of magnetic fields in which negative dip-needle readings are obtained. In one type high negative readings are obtained scattered among equally high positive readings. These are usually interpreted as being derived from greenstone or from bodies like the Gunflint inclusions described above, where the magnetite is bunchy, and close to the surface. In other cases, there may be a narrow zone of negative readings due to a local lowered field intensity, along a line of the usual positive type. These types of negative readings are common and not difficult to recognize, and should not cause concern. However, the type of negative field shown in Fig. 14 is exceedingly rare. Its description and interpretation is given below.

Negative Lines.—Fig. 14 shows a magnetic line of negative attraction. It is to be noted that the only positive readings obtained were entirely local and erratic and constituted a fraction of a per cent. of all the readings taken. Authorities on magnetics agree that it is not uncommon to have a positive line along which there is a zone of negative readings. However, this line differs essentially from those which are partly positive and partly negative. Hotchkiss[5] has described a similar line which was found in Wisconsin. This line can be followed for about five miles. A few miles south there is a positive line. The two converge to the eastern part of the area. Hotchkiss suggests that the structure of the magnetic body is synclinal, pitching westward. Dobie[6] suggests the following as an explanation of the negative character of the line. Magnetite has high magnetic

[4] Hotchkiss, W. O., *op. cit.*, p. 103.

[5] Hotchkiss, W. O., *op. cit.*, p. 341.

[6] Dobie, Walter, unpublished thesis written at the University of Wisconsin.

retentivity. Therefore, when a magnetic formation becomes polarized by induction in the usual manner, its negative pole being near the outcropping part of the formation, it may retain its original polarity even if it should become folded and eroded so that its formerly buried positive pole would be brought near to the surface. It should be kept in mind that an outcropping negative pole attracts the positive end of the dip needle, giving a positive line and vice versa. On the basis of this theory, he considers that the southern positive line is obtained from the original outcropping negative pole, and the northern negative line from the originally buried positive pole of the formation, brought to the surface by folding and erosion.

It would be almost impossible to interpret magnetic readings if it were necessary to explain any magnetic observations on such a basis. In all such interpretations up to this time it has been assumed that the character of the magnetic field above an ore body is determined by the magnetism induced by the earth's magnetic field in the ore since it attained its present position. On this assumption it is supposed to be possible to determine approximately the dip, strike, depth of burial, and size of ore bodies. If it should be found that the magnetic field around any formation in the Lake Superior region were conditioned in any way by a previous attitude of the formation, such determinations would be impossible. All the disturbed formations in the Lake Superior region, and there are few which are not disturbed, would give effects of a magnetism induced in them before they were deformed.

However, there are several objections to Dobie's theory. In the first place, it is possible that the magnetite was formed originally at the time of the dynamic action, so that the structural position of the magnetite at the present time is the only position which it has ever occupied. Granting that the magnetite of the formation may have existed when it formerly occupied another position in the earth's magnetic field, it would seem unlikely that it would retain the induced polarity after suffering dynamic action. Deformation of any particular rock takes place in the

zone of fracture or in the zone of flowage for that rock. If the magnetite bed were folded in the zone of fracture, it would have suffered intense mechanical disturbances, such as crushing and abrasion. This would tend to throw the parts of the formation entirely out of alignment, rotating them into haphazard positions, thus completely destroying the magnetic identity of the formation as a whole. If the folding took place by flowage, the process would be even more effective in destroying the magnetic properties of the body. Folding in the zone of flowage takes place by recrystallization, which involves molecular movement. Assuming that magnetite is magnetic under the conditions of rock flowage, the effect of the increased molecular mobility would be to give the molecules greater freedom in magnetically orienting themselves according to the demands of the changing positions which the formation would occupy with respect to the earth's magnetic field during folding. This would result in the destruction of the original magnetic properties of the body. However the magnetic inversion point of polarized magnetite is about 550° C.,[7] which would be exceeded in the zone of flowage. At this temperature polarized magnetite begins to lose its magnetism, and is no longer even capable of being attracted by a magnet. Although on cooling it regains its susceptibility to being attracted, it does not regain its polarity. In order to be polarized again, it must be properly treated in a magnetic field and the polarity it thus acquires is in no way related to that which it had before being heated. Finally, it would seem improbable that a magnetic body could remain in magnetic discordance with the field which originally magnetized it, throughout Keweenawan and post-Cambrian times. The earth movement which would form a syncline of this sort was probably pre-Keweenawan.

It is therefore necessary to attempt to explain the character of the few known negative lines on the same basis upon which we explain the magnetic properties of other iron formations, that is, that the magnetic phenomena shown by such bodies are due to their present position in the earth's field. Fortunately, the

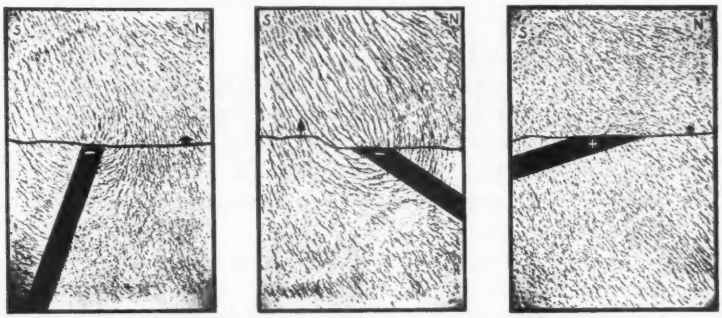
[7] Sosman, R. B., "Some Problems of the Oxides of Iron," *Jour. Wash. Acad. Sci.*, Vol. 7, p. 63, 1917.

features of the magnetite bodies which form the several negative lines in the Duluth gabbro which have been investigated and mapped in great detail are simple and known. There is no drift, and outcrops along the lines are numerous. The bed rock is everywhere within a few feet of the surface, which is nearly flat in the vicinity of many of the ore bodies. The width of the magnetite bands is fairly constant. One of the lines will serve for an example of the type. The strike of the magnetite band is a little south of east. It dips about 15° to the south and extends so far in depth that the buried magnetic pole does not affect the instruments. Its width, across the dip, is about four feet. The width of outcrop is thus about fifteen feet. It grades into lean gabbro at the top and bottom, and at each end. The topography is level for some distance on each side of the belt. It can be followed by magnetic observations for about a mile. The explanation of negative lines, advanced by Dobie, could not be applied here, because, in addition to the objections urged above, the folding of the Keweenawan gabbro has been very slight.

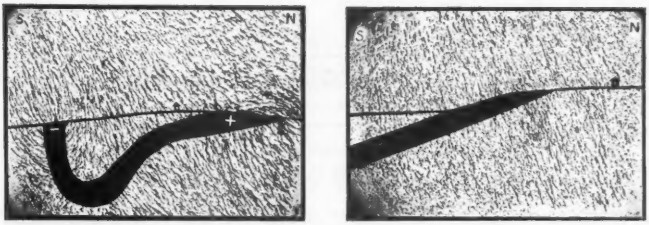
Dip needle readings were taken every 12½ feet over the entire belt. Fig. 14 is a dip contour map of a part of the line. Instead of the outcropping pole being a negative pole, as it is in the ordinary case, it is a positive pole, attracting the negative pole of the dip needle. Theoretically, the conditions under which this may occur are very limited.

In order to show experimentally what these conditions would be, the types of disturbance of some fairly uniform magnetic fields by a bundle of soft iron wires placed at various angles in them were investigated. The field in these diagrams was produced by a series of bar magnets in parallel position, and it may be considered as representing the earth's magnetic field. The bundle of wires is intended to denote an iron formation in the earth, outcropping as shown in the figures. Care was taken to render the wires absolutely neutral before each experiment. In Figs. 17 and 18 the outcrop shows that an iron formation in these positions would attract the north end of the needle, that is, the magnetic line obtained from a formation dipping as these do

would be essentially a positive line. The lines of force converge and enter the outcrop in these cases, making the induced polarity at the outcrops negative. Fig. 19 shows the opposite effect. The lines of force of the field are actually repelled by the end of the



17 18 19



22 23

FIGS. 17, 18, 19, 22, AND 23. Experiments designed to show the distortion of the earth's magnetic field by tabular bodies of magnetite lying in various altitudes.

"iron formation." A counterbalanced dip needle would have its south end depressed over the outcrop, and for some distance to the north and south. The polarity of the outcrop would be positive in this case.

These diagrams show that it is experimentally possible to pro-

duce "outcrops" which would give either positive or negative lines, by varying the inclination of the bar to the field. In some cases, a negative line, then, may be capable of being interpreted as caused by a magnetic formation whose angle of dip lies within certain limits. To be able to say just what these limits are would be of great practical value in exploration work, in case other similar lines should be found.

The following suggestions are made bearing on the probable angles of dip which would give the negative lines. A neutral bar of a magnetic substance, placed in parallel position in a magnetic field, acquires an induced polarity (Fig. 20 *a*). The posi-

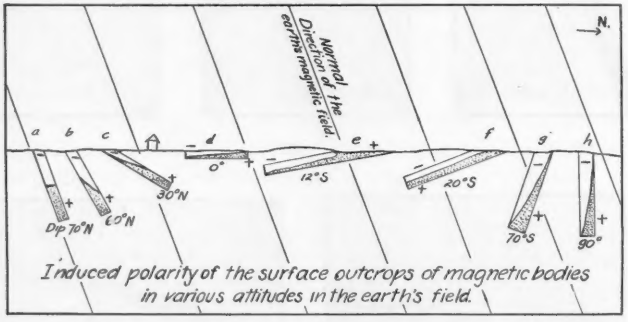


FIG. 20. Induced polarity of the surface outcrops of magnetic bodies in various attitudes in the earth's field.

tive pole would be at (or very near) the end of the bar which lies in the direction in which a free moving north seeking pole in the field would move. As the bar is rotated from the parallel position, the polarity becomes related more and more to the sides, and less to the ends, until finally, when the bar is perpendicular to the field, it is entirely related to the sides (Fig. 20 *f*). However, if the bar is turned but a few degrees from the perpendicular position, the ends will show some polarity. In order to make the application to magnetic bodies in the earth clear, the inclination of the lines of the field (drawn undistorted in this figure) with the horizontal has been made 70°, approximately the incli-

nation of the earth's field in the Lake Superior region. The horizontal line represents the surface, and the upper end of the bar the outcrop of a magnetic formation. The theoretical limitations of the dip of formation which would give a negative line can be deduced from the figure. In the positions *d, e, f,* the bar makes an angle of 70°, 82°, and 90° with the field. These angles correspond to a dip of 0°, 12°, and 20° to the south. Dips between the theoretical limits of 0° and 20° south would give a negative line, because the outcrop has north polarity. If the normal inclination of the earth's field were 75°, the limitations would be 0° to 15° dip to the south. A point deep within the earth on these beds would actually be "up-stream" in the earth's field as compared with a point on the outcrop of the beds. These limits assume a horizontal surface. If the surface rises to the south, there would be more freedom. Fig. 21 shows a hypothetical case which would give a negative line over the northern out-

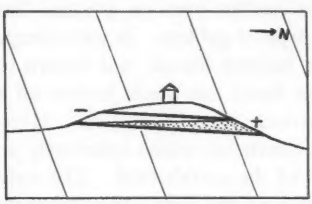


FIG. 21. Positive pole of north dipping magnetic body exposed by erosion.

crop of a formation dipping gently to the north. Fig. 22 shows a structure which might produce a negative line similar to that described by Hotchkiss, the flat southward dipping limb of the syncline affording the negative line and the northward dipping limb the positive line.

This explanation of negative lines is given strong support by the results of recent work of the Minnesota Geological Survey on the magnetite ores of the eastern Mesabi range. There the Biwabik iron-bearing formation dips about seven degrees to the south. The magnetic field is not so simple as those produced by the narrow bands in the gabbro, due to the variable nature of

the different beds of the Biwabik formation, several hundred feet in thickness. In spite of this, the great majority of several thousand dip-needle readings were negative. Since the dip of the formation is about seven degrees to the south, this result is what would be expected if the proposed explanation of negative lines is correct.

Magnetic Bodies with No Attraction.—If a few degrees difference in the angle of dip of an iron formation is sufficient to change the character of the dip-needle variations from positive to negative, theoretically there should be an intermediate angle of dip such that there would be no effect upon the earth's field. This rare condition was discovered in the magnetites of the gabbro. It was found that there were long east-west bands of titaniferous magnetite ore outcropping on a south-facing slope, with practically the same southward dip, dimensions, etc., as the one which gave the negative belt described above, over which the variations of the needles were no greater than those obtained over the normal type of gabbro. It was thought that this might be pure ilmenite, because the ore was known to be high in titanium, until it was found that pieces broken off and held near the needles had a marked influence on them. Here, then, were outcrops of magnetic material, which apparently produced no measurable distortion of the earth's field. The writer has not heard of any other cases of the sort. Fig. 23 shows an attempt to duplicate these conditions. A soft iron bar, bevelled as shown, was placed in a field at right angles to its direction of lines of force. There was no noteworthy distortion of the field. The dip of these bands of magnetite which gave no magnetic variations, as closely as could be determined, was about 18° south, just about at right angles to the earth's field, as in the hypothetical case of Fig. 23. Therefore a magnetic formation at right angles to the earth's field would not affect the dip needle, and in a drift-covered region would probably remain undiscovered.

Summary.—On the whole, though one may be inclined to doubt that the change of a few degrees of dip of a formation would be sufficient to change the character of the resultant mag-

netic line from positive to negative, the theory appears to have some support. In the case of the gabbro ores, where the absence of drift allows the various factors involved to be determined, field evidence seems to favor this interpretation and experiments essentially reproducing actual conditions give further evidence of the validity of the theory. The rarity of negative lines is wholly in agreement with the explanation of the conditions governing them; the proper angle of dip is seldom obtained in the field.

SOME CHEMICAL EXPERIMENTS BEARING ON THE ORIGIN OF CERTAIN URANIUM–VANADIUM ORES.

FRANK B. NOTESTEIN.

Carnotite is found in many geological environments and is probably formed in several ways. At Radium Hill, near Olary, Australia,[1] it is associated with minerals which were probably deposited by hot solutions. In these deposits it fills cavities and coats the walls of crevices and may have been formed by secondary processes from the associated primary minerals. In the United States it is found far removed from igneous rocks, and its ores are supposed to have been deposited by cold ground water solutions or to be alteration products, in place, of vanadium and uranium bearing sediments. The secondary character of carnotite is practically undisputed, although the primary minerals from which the American deposits are derived are uncertain.

The relative importance of the two suggested modes of origin is still in doubt. This report deals with an investigation of certain natural solvents and precipitants of vanadium and uranium, which are believed to throw some light on possible processes involved in at least one of the suggested modes of origin.[2]

[1] Crook, T., and Blake, G. S., "On Carnotites and an Associated Mineral Complex from South Australia." *Min. Mag.*, Vol. 15, p. 271, 1910.

[2] Some of the more important publications are:

Hillebrand, W. F., and Ransome, F. L., "Carnotite and Associated Vanadiferous Minerals in Western Colorado," U. S. Geol. Survey Bull. 262, pp. 9–31.

Boutwell, J. M., "Vanadium and Uranium in Southeastern Utah," U. S. Geol. Survey Bull. 260, pp. 200–210.

Gale, H. S., "Carnotite in Rio Blanco County, Colorado," U. S. Geol. Survey Bull. 315, pp. 110–117.

Gale, H. S., "Carnotite and Associated Minerals in Western Routt County, Colorado," U. S. Geol. Survey Bull. 340, pp. 257–262.

Moore, Richard B., and Kithil, Karl L., "A Preliminary Report on Uranium, Radium, and Vanadium," U. S. Bureau of Mines Bull. 70.

Carnotite is essentially a vanadate of uranium and potassium. Other bases, especially calcium and barium, and several of the metals, are thought to replace part of the potassium in some cases. Hess[3] gives the formula for carnotite as $K_2O \cdot 2UO_3 \cdot V_2O_5 \cdot XH_2O$. It is usually associated with and probably forms isomorphous mixtures with tyuyamunite,[4] $CaO \cdot 2UO_3 \cdot V_2O_5 \cdot XH_2O$. The carnotites are nearly always associated with amorphous ores of vanadium containing minor amounts of uranium. The composition of these ores is uncertain, but they are probably oxides and silicates.

The principal carnotite deposits of the United States are located in the plateau country of southwestern Colorado and southeastern Utah. Of these the most productive occur in or near the Paradox Valley, Colorado. Others are worked at several points in southern Utah. Minor deposits have been discovered in northwestern Colorado. A deposit so far of no commercial importance is located near Mauch Chunk, Pa. Carnotite also occurs as an accessory mineral in the roscoelite[5] deposits near Placerville, southwestern Colorado.

Fleck, Herman, and Haldane, William G., "A Study of the Uranium and Vanadium Belts of Southern Colorado," Report of the State Bureau of Mines, Colorado, 1905–1906.

Wherry, Edgar T., "Carnotite near Mauch Chunk, Pennsylvania," Bull. U. S. Geol. Survey No. 580, pp. 147–151.

Hess, F. L., "A Hypothesis for the Origin of the Carnotites of Colorado and Utah," ECON. GEOL., Vol. 9, pp. 675–688.

Hess, F. L., "Notes on the Vanadium Deposits near Placerville, Colorado," U. S. Geol. Survey Bull. 530, pt. 1, pp. 142–156.

Hess, F. L., "Vanadium in the Sierra De Los Caballos, New Mexico," U. S. Geol. Survey Bull. 530, pt. 1, pp. 157–160.

Hess, F. L., "Carnotite near Green River, Utah," U. S. Geol. Survey Bull. 530, pt. 1, pp. 161–164.

Lindgren, Waldemar, "Copper, Silver, Lead, Vanadium, and Uranium Ores in Sandstone and Shale," ECON. GEOL., Vol. 6, pp. 568–581.

Emmons, W. H., U. S. Geol. Survey Bull. 625, pp. 432–435.

Crook, T., and Blake, G. S., "On Carnotite and an Associated Mineral Complex from South Australia," *Min. Mag.*, Vol. 15, p. 271, 1910.

[3] Hess, F. L., "A Hypothesis for the Origin of the Carnotites of Colorado and Utah," ECON. GEOL., Vol. 9, pp. 675–688.

[4] *Idem.*

[5] Hess, F. L., "Notes on the Vanadium Deposits near Placerville, Colo.," Bull. U. S. Geol. Survey No. 530, Pt. 1, pp. 142–156.

CHARACTER OF THE DEPOSITS.

The Colorado and Utah deposits are in white to buff, moderately coarse, cross-bedded sandstones of Jurassic age. The beds are usually flat or dip at low angles, but a few deposits are in beds which dip steeply. The productive beds are hard and massive enough to form the canyon rims and hogbacks so characteristic of western slope topography. Exposures therefore are abundant. The carnotite in these deposits is an amorphous dusty coating on, or matrix between, grains of sand. It also coats the rock along joint planes and fractures, and fills openings caused by rock movements.

The carnotite deposits are small and lenticular, and conform to the bedding planes of the rock. They are rarely over 100 feet in lateral extent and vary from a few inches to several feet thick. Their distribution is very irregular. Many of the deposits are interbedded with thin beds containing dark colored amorphous ores of vanadium with only small amounts of uranium. Some, also, are found above thin shales.

Nearly all of the ore-bearing beds are notably rich in fossil material made up largely of either petrified or carbonized wood. Thin beds of carbonaceous material occur in which the fossils are indistinct but in which ferns and rushes have been recognized. The carbonaceous material is commonly rich in vanadium, and petrified logs partly replaced by carnotite have been found. The apparent abundance of carbonaceous material and plant fossils in the ore-bearing beds is suggestive in view of the occurrences elsewhere of vanadium in coals, asphalts, and also in plant ashes.[6] However the abundance of carbonaceous material in carnotite deposits is not universal and may have no generic significance. The McElmo formation, in which the Paradox Valley carnotite deposits occur, carries abundant petrified wood where exposed near Norwood, Colorado (between Placerville and Paradox Valley), but no carnotite has yet been discovered in that locality.

[6] Clarke, F. W., "The Data of Geochemistry," U. S. Geol. Survey Bull. 616, p. 705.

The ore-bearing sandstones are cemented by silica, calcite and gypsum,[7] the cement probably varying from place to place. It is, of course, probable that much original calcite has been replaced by silica or converted to gypsum by sulphate ground waters.

The carnotite deposits typically occur in "rim rocks" along the sides of canyons, and the ore almost universally dies out when followed a short distance into the hill. The deposits appear to be very superficial, a characteristic which was emphasized by Ransome,[8] who suggested, also, that the arid condition of the climate might have something to do with this surface deposition. However, a few pockets have been discovered which did not outcrop. There are also deposits which occur on gently dipping mesa surfaces, the ore being so close to the surface as to be worked by open cut. The shallow overburden of many of the deposits suggests that much might be learned about the extent and distribution of the deposits by systematic drilling. Whether the apparent relation to surface outcrops along canyons is an essential feature or not can be determined only by deeper and more systematic underground exploration than has yet been done.

It has been shown by several writers who have discussed the subject that carnotite is deposited along fracture lines within the ore-bearing beds even where the fractures are very recent and due to slumping on hillsides.[9] This condition points to solution by descending ground waters and to redeposition on exposure to air.

The deposit at Mauch Chunk, Pa., is in Pottsville conglomerate just above its contact with shales. The carnotite is associated with lenses of black vanadiferous shale. Wherry[10] states that "the mineral presents the form of an amorphous to minutely crystalline bright yellow coating or impregnation in a conglom-

[7] Hess, F. L., "A Hypothesis for the Origin of the Carnotites of Colorado and Utah," ECON. GEOL., Vol. 9.

[8] Hillebrand, W. F., and Ransome, F. L., *op. cit.*

[9] Hillebrand, W. F., and Ransome, F. L., *op. cit.*

[10] Wherry, Edgar T., "A New Occurrence of Carnotite," *Am. Jour. Sci.*, 4th Ser., Vol. 33.

erate, often penetrating cracks in quartz pebbles." He says further of this deposit "It is evidently simply a precipitate from the ground water and can be seen in the process of formation where water trickles out from the cracks in the rocks."[11] An analysis of this ground water would be of very great interest.

ORIGIN OF THE DEPOSITS.

Because the principal carnotite deposits are distant from igneous rocks the possibility of origin through hydrothermal action has generally been rejected. Hess,[12] however, considers this hypothesis in connection with the southwestern deposits.

Three hypotheses of origin have been advocated, as follows:

1. First, that minerals carrying vanadium and uranium were widely disseminated, by mechanical sedimentation or chemical precipitation through the beds now, or formerly, overlying the ore-bearing rocks and that these minerals have been dissolved by ground waters and the metals carried down and reprecipitated at the position where now found through some such agency as calcite or organic matter or through oxidation near outcrops. Ransome[13] states that "the recency of the deposits and the fact that they are sometimes directly connected with faults and dislocations in the sandstones show that the vanadium and uranium compounds could not have been the original cementing material of the quartz grains, but in all probability they have locally replaced the calcite that acts as a matrix to the ordinary light-colored sandstones in which the ore bodies occur." While developments have shown that the sandstone is not universally cemented with calcite, yet this hypothesis seems very plausible as applied to many of the reported occurrences. Moore[14] and Kithil adopt essentially this hypothesis and show that the radioactivity of the beds overlying the carnotite deposits is much greater than that of

[11] Wherry, Edgar T., "Carnotite near Mauch Chunk, Pennsylvania," U. S. Geol. Survey Bull. 580, pp. 147–151.

[12] Hess, F. L., "Vanadium Deposits near Placerville, Colorado," U. S. Geol. Survey Bull. 530, Pt. 1, p. 154.

[13] Hillebrand, W. F., and Ransome, F. L., *op. cit.*

[14] Moore, Richard B., and Kithil, Karl L., *op. cit.*

ordinary sandstones. They also observe that the richness of the deposit seems to bear a direct relation to the thickness of the overburden.

Gale[15] and Lindgren[16] support the hypothesis of concentration of these ores by circulating ground waters. Hillebrand[17] has shown that vanadium is widely disseminated in small quantities in both igneous and sedimentary rocks.

2. Second, that minerals carrying vanadium and uranium were concentrated by ordinary processes of sedimentation at or near the present position of the ore, and that the carnotite is an oxidation product of such minerals. Fleck and Haldane,[18] while not expressing a definite opinion, seem inclined to this view. Wherry[19] also supports this hypothesis for the Pennsylvania deposit.

3. A third hypothesis suggested tentatively by Hess[20] assumes that vanadium and uranium were originally precipitated from solution in sea water by the reducing action of decaying vegetable matter and that the carnotite is essentially an oxidation product, practically in place, of such precipitated uranium-vanadium salts. He lays special stress on the abundance of organic remains as the only characteristic common to all the deposits and argues that the carnotite replaces only those parts of petrified logs which were decayed before petrifaction.[21] From this he deduces that the replacement took place along with sedimentation.

[15] Gale, H. S., "Carnotite in Rio Blanco County, Colorado," U. S. Geol. Survey Bull. 315, p. 116.

[16] Lindgren, Waldemar, *op. cit.*

[17] Hillebrand, W. F., "Distribution and Quantitative Occurrence of Vanadium and Molybdenum in Rocks of the United States," *Am. Jour. Sci.*, 4th Series, Vol. 6, pp. 209–216.

[18] Fleck, Herman, and Haldane, Wm. G., *op. cit.*

[19] Wherry, Edgar T., "Carnotite near Mauch Chunk, Pennsylvania," U. S. Geol. Survey Bull. 580, pp. 147–151.

[20] Hess, F. L., "A Hypothesis for the Origin of the Carnotites of Colorado and Utah," ECON. GEOL., Vol. 9.

[21] Gale, in describing the deposits in N. W. Colorado, in Rio Blanco County, takes a different view. See U. S. Geol. Survey Bull. 315, p. 116.

EXPERIMENTAL WORK.

An effort has been made to ascertain what natural solvents might be expected to dissolve and transport uranium and vanadium, and what natural precipitants might be expected to precipitate these metals from the most probable solvents.

It has been shown[22] that ground waters may be classed as solutions of chlorides, carbonates and sulphates. Accordingly tenth normal solutions of several chlorides, carbonates and sulphates were prepared and finely divided carnotite was leached for various periods. The carnotite ore used was rich in calcite and iron and contained some gypsum. The mineral was prepared by sifting partly crushed ore through a 200-mesh sieve in order to eliminate as much as possible of the sandy gangue material. In each test 30 c.c. of the solution was placed in a bottle with about one gram of the finely divided carnotite. The bottles were shaken at frequent intervals during the leaching period.

All the results of these tests of solvents are based on qualitative tests with equal amounts of material, and statements of relative solubility are based on colorimetric comparison which cannot be considered quantitatively accurate. The tests used are, however, fairly delicate and negative results mean that neither metal was dissolved.[23]

It is plain that pure water and solutions of alum, chlorides, the normal alkali sulphates, and calcium sulphate in water have no solvent action on the mineral. The solutions of bicarbonates and bisulphates have a very slight solvent effect. Tenth normal sulphuric acid dissolves carnotite fairly rapidly, and its solvent action is increased by the addition of the alkali sulphates, alkali

[22] Emmons, W. H., and Harrington, G. L., "A Comparison of Waters of Mines and of Hot Springs," Econ. Geol., Vol. VIII., No. 7, pp. 653–669.

[23] For methods of testing for vanadium and uranium see Roscoe and Schorlemmer, "Treatise on Chemistry," pp. 942 and 1121.

The test for uranium was modified in one respect: The ammonium carbonate filtrate was very slightly acidified instead of "supersaturated" with hydrochloric acid.

All of the samples were tested at the end of twenty-four hours and gave results essentially the same as at the end of the period of leaching. Hence the length of the period of leaching is believed to be unimportant.

TABLE I.

Mineral.	Solution.	Period Leached, Days.	Result.
Carnotite 200-mesh	Distilled H_2O	30	No vanadium or uranium dissolved.
	N/10 NaCl in H_2O	30	" " " " "
	N/10 KCl in H_2O	60	" " " " "
	N/10 $NaHCO_3$ in H_2O	30	Trace of vanadium and uranium dissolved.
	N/10 $KHCO_3$ in H_2O	60	Trace of vanadium and uranium dissolved.
	N/10 Na_2CO_3 in H_2O	15	No vanadium or uranium dissolved.
	N/10 K_2CO_3 in H_2O	15	" " " " "
	N/10 K_2SO_4 in H_2O	15	" " " " "
	N/10 $Na_2SO_4.10H_2O$ in H_2O	15	" " " " "
	Saturated Solution $CaSO_4.2H_2O$ in H_2O	15	" " " " "
	N/10 $KHSO_4$ in H_2O	15	Strong trace of vanadium and uranium dissolved.
	N/10 $NaHSO_4$ in H_2O	15	Strong trace of vanadium and uranium dissolved.
	N/10 potassium alum in water	60	No uranium and vanadium dissolved.
	N/10 H_2SO_4	30	Some uranium and vanadium dissolved
	N/10 $FeSO_4$ in N/10 H_2SO_4	30	" " " " "
	N/10 $Fe_2(SO_4)_3$ in N/10 H_2SO_4	30	Considerable uranium and vanadium dissolved.
	N/10 K_2SO_4 in N/10 H_2SO_4	15	Considerable uranium and vanadium dissolved.
	N/10 $Na_2SO_4.10H_2O$ in N/10 H_2SO_4	15	Considerable uranium and vanadium dissolved.
	$CaSO_4$ in N/10 H_2SO_4	15	Considerable uranium and vanadium dissolved.
	N/10 $KHSO_4$ in N/10 H_2SO_4	15	Considerable uranium and vanadium dissolved.
	N/10 $NaHSO_4$ in N/10 H_2SO_4	15	Considerable uranium and vanadium dissolved.
	H_2S in Na_2CO_3 solution	5	No vanadium or uranium dissolved.
	H_2S in H_2O	5	" " " " "
	H_2S in N/10 H_2SO_4	5	" " " " "
	Saturated solution NaCL in H_2O	5	" " " " "
	$CaCO_3$ in H_2O	5	" " " " "

bisulphates, calcium sulphate, and ferric sulphate. The effect of ferrous sulphate appears to be negative.

Hydrogen sulphide in alkaline, acid, and water solution had no solvent effect, but it converted the mineral to a black colloidal substance some of which remained in suspension for hours after shaking. This substance was probably a sulphide.[24]

[24] Bird, R. M., and Calcott, W. S., "The Association of Vanadium with Petroleum and Asphalt," Univ. of Va. Bull. Philos. Soc., Scientific Series, Vol. 1, No. 18.

The very slight solubility of carnotite in alkali bicarbonates makes it improbable that they have been primary agents in the transportation of the metals. Sulphide solutions are also eliminated as solvents although colloidal uranium-vanadium compounds might perhaps be transported mechanically where the circulation was rapid and rocks porous.[25]

The above results show that sulphate ground waters are quite capable of transporting uranium and vanadium, especially where the solutions carry alkali sulphates, with which these metals readily form soluble double sulphates.[26]

With these results as a basis a mixture containing equal parts of approximately tenth normal aqueous solutions of vanadyl sulphate, $V_2O_2(SO_4)_2$,[27] and a soluble uranyl disulphate, $UO_2S_2O_7$[28] (?) and K_2SO_4, was prepared and an effort was made to synthesize carnotite from this solution by the use of various precipitants.

Thirty c.c. of the solution described above were placed in a dish and several grams of calcite were added. Carbon dioxide was evolved at once and a fine yellow cloudy precipitate came down slowly. After 48 hours the solution was neutral, and there was a heavy yellow precipitate. This precipitate was filtered, washed and dried. It has not been quantitatively analyzed, but qualitative test show it to contain abundant vanadium and uranium, and it also contains small amounts of carbonates and sulphates. The latter is supposed to be precipitated gypsum. The compound is very probably a mixture of carbonates and vanadates, but it is not carnotite since it is soluble in dilute carbonate solutions.

The solubility of the above described precipitate, hereinafter called "precipitate A" for convenience, was tested as shown in Table II.

[25] *Idem.*

[26] Emmons, W. H., "The Enrichment of Ore Deposits," U. S. Geol. Survey Bull. 625, p. 435.

[27] Roscoe and Schorlemmer, "Treatise on Chemistry," Vol. 1, p. 938.

[28] Roscoe and Schorlemmer, "Treatise on Chemistry," Vol. 1, p. 1118.

TABLE II.

TABLE SHOWING TESTS OF SOLUBILITY OF PRECIPITATE A.

Solution.	Period Leached.	Results.
Distilled water	48 hours	Insoluble.
Distilled water CO_2 was passed through for one hour	" "	"
N/10 Na_2CO_3 in water	" "	Fairly soluble.
N/10 Na_2CO_3 in water CO_2 was passed through one hour	" "	Very soluble.
N/10 $KHCO_3$ in water	" "	Fairly soluble.
Pure $CaCO_3$ in water	" "	Insoluble.

Chemically pure calcium carbonate was placed in a bottle with a small amount of precipitate A, distilled water was added, and carbon dioxide was passed through for several hours. This resulted, of course, in a solution of calcium bicarbonate. The material was then filtered and the filtrate divided into two parts. One part was boiled violently for fifteen minutes to drive off the carbon dioxide. The solutions were then tested qualitatively for uranium and vanadium. A trace, only, of vanadium was found in both. In the part from which the carbon dioxide had been driven off there was a faint trace of uranium while in the half still containing calcium bicarbonate in solution there was abundant uranium in solution. Obviously precipitate A is soluble in alkali earth carbonates but since calcium carbonate is practically insoluble in pure water it can act as a solvent only when in solution as a bicarbonate—in the presence of carbon dioxide.

As would be expected precipitate A is readily soluble in dilute sulphuric or hydrochloric acids.

From the above tests of the solubility of precipitate A in calcium bicarbonate it is clear that if it were naturally precipitated in a calcareous bed the uranium at least could be redissolved and transported in solution with calcium bicarbonate, but it would be reprecipitated whenever the solution reached the surface or fissures through which the carbon dioxide could escape.

Coal and rotten wood have not caused any visible precipitation after having stood in a solution of uranium-vanadium-potassium sulphate for over 20 days. Evidently they react very slowly, if at all.

In another experiment 10 c.c. of tenth normal uranyl sulphate

and 10 c.c. of potassium sulphate were mixed in a bottle and approximately one tenth gram of vanadium pentoxide was added. After standing twenty-four hours there was a heavy yellow precipitate in the bottom of the bottle. This experiment has not been followed up, but it indicates the possibility that vanadium oxides may act as precipitants of uranium compounds, presumably because the higher oxides of vanadium are powerful oxidizing agents.

SUMMARY.

1. Carnotite is readily soluble in ground waters carrying free sulphuric acid and alkali sulphates and bisulphates. It is very slightly soluble in weak solutions of alkali bicarbonates, but is insoluble in most solutions of normal alkali bicarbonates, chlorides, normal alkali sulphates, and hydrogen sulphide.

2. Calcite readily precipitates vanadium and uranium from vanadyl and uranyl sulphate solutions. The precipitate thus formed is readily dissolved by solutions of alkali carbonates and bicarbonates and by a solution of calcium bicarbonate. In the latter solution the loss of carbon dioxide results in the precipitation of both lime and the metals.

Rotten wood and coal have so far failed to precipitate either metal. This point should be tested further. Vanadium pentoxide, acting as an oxidizing agent, precipitates uranium from a solution of uranyl sulphate.

GEOLOGICAL APPLICATION.

Unfortunately no analyses of the ground waters from the region of the carnotite deposits are available. Emmons[29] mentions the ocurrence of springs carrying saline and alkaline waters and hydrogen sulphide within the region where these ores occur but no analyses were made. Lindgren[30] states: "The waters which traverse sedimentary rocks are often rich in salts, par-

[29] Emmons, W. H., "The Cashin Mine, Montrose County, Colorado." U. S. Geol. Survey Bull. 285, p. 127.

[30] Lindgren, Waldemar, "Mineral Deposits," p. 52.

ticularly in sulphates." He says also: "Sodium sulphate waters are almost characteristic of certain formations in the western Cretaceous, for instance: these formations consist mainly of sandstones and carbonaceous shales, the latter often pyritiferous, and the whole series mainly a product of near-shore deposition. The oxidation of the pyrite furnishes solutions containing free sulphuric acid." This description applies excellently to the McElmo formation in and immediately below which the carnotite deposits are located. The base of the Cretaceous in southwestern Colorado is rarely more than 1,000 feet, stratigraphically, above the ore-bearing horizon and in many places it is less than that. The base member of the Cretaceous in this region almost invariably carries a bed of pyritiferous lignite. It is true, of course, that the carnotite beds now normally have a very shallow overburden but there is no reason to doubt that they have been overlaid by the Cretaceous beds within a period which is geologically short. The abundance of crystalline gypsum[31] in association with plant remains in these deposits is important. The plant remains seem to indicate that the arid conditions necessary for precipitation of gypsum from sea water did not prevail at the time of sedimentation. It follows that the crystalline gypsum is of secondary origin and that sulphate-bearing ground waters have been active in these beds. The sulphuric acid probably was derived by oxidation of pyrite in carbonaceous beds.

It is reasonable to suppose then that descending sulphate waters would dissolve any disseminated uranium and vanadium present in the beds through which they passed and that these metals would be precipitated from solution by the first calcareous bed encountered. Assuming the ground water to carry free sulphuric acid the reaction would produce crystalline gypsum and carbon dioxide as well as the uranium-vanadium precipitates. In view of the frequent occurrence of both calcite and gypsum in carnotite deposits it is probable that many of the deposits have formed in this manner.

The solubility of precipitate "A" in calcium bicarbonate solu-

[31] Moore, Richard B., and Kithil, K. L., *op. cit.*, pp. 12, 17, 22, 24, 25, 27.

tions suggests an explanation of the apparent superficial character of the deposits. Assuming that sulphate ground waters carrying uranium and vanadium in solution meet calcareous beds the first result would be the production of crystalline gypsum, carbon dioxide, and the uranium-vanadium precipitate. The second result would be the formation of calcium bicarbonate which would redissolve the uranium and, to a certain extent, the vanadium. The further transportation would, of course, be in the direction of ground water circulation. In a region of flat beds cut by deep canyons there must be a strong lateral circulation along permeable beds and above impermeable shales. This lateral circulation is due not only to gravity but to capillary attraction induced by rapid evaporation along outcrops. Assuming a calcium bicarbonate solution to be drawn laterally toward an outcrop it would transport any dissolved uranium and vanadium until the carbon dioxide escaped either at the surface or along fracture lines. On the escape of carbon dioxide both lime and the metals would be thrown down and the metals would probably oxidize, where close to the surface, by contact with air. In cross-bedded rocks the channels of ground water circulation would naturally be very irregular, hence the pockety nature of the deposits. If this hypothesis is correct it would be expected that on following a carnotite deposit into the hill the vanadium values would be more persistent than the uranium values since the latter, being more soluble in bicarbonates, would be more readily concentrated near the surface.

Summarizing, it has been shown that:

1. Uranium and vanadium are soluble in ground water carrying sulphates.

2. There is good evidence for believing that sulphate ground waters have been active in the beds where the carnotite ores are found or at least in those immediately overlying them.

3. Calcite precipitates uranium and vanadium from sulphate solutions.

4. This precipitate is soluble in calcium bicarbonate solutions but is reprecipitated by the loss of carbon dioxide.

5. Calcite and gypsum are characteristic of many of the carnotite deposits.

The above facts suggest the following mode of origin for many of the carnotite deposits.

1. Descending sulphate waters dissolve disseminated uranium and vanadium minerals and the metals are carried down in the ground water circulation.

2. When this ground water solution meets a calcareous bed the metals are precipitated, gypsum is formed, and carbon dioxide is liberated.

3. Carbon dioxide in solution would form calcium bicarbonate which would redissolve the uranium and to some extent vanadium salts.

4. These salts would be reprecipitated and would tend to remain undissolved at or near outcrops or wherever there was opportunity for the escape of carbon dioxide.

This is essentially the hypothesis of Ransome.[32] It seems to apply where the ore-bearing beds are characteristically calcareous but not so directly to those deposits whose matrix is siliceous.

A corollary of this hypothesis is that carnotite would be concentrated along joint places and fracture or fault lines both because they are channels of water circulation and because they offer means of escape of carbon dioxide. It is suggested that a study of the jointing system might aid prospecting.

The above hypothesis of origin may not apply to all of the western deposits and its validity as applied to any of them can be determined only by systematic study of the deposits and of the overlying beds. More complete data is desirable on the following points especially:

1. The exact character of the ground waters in the ore-bearing beds.

2. The character of the matrix of the ore-bearing rocks and of the overlying beds.

[32] Hillebrand, W. F., and Ransome, F. L., "Carnotite and Associated Vanadiferous Minerals in Western Colorado," U. S. Geol. Survey Bull. 262, pp 9–31.

3. Local conditions governing ground water circulation, as the abundance of shales underlying the ore-bearing beds, circulation due to capillarity, and localization of ground water circulation by cross bedding.

4. Abundance of pyritiferous beds in the rocks overlying, or formerly overlying, the ore-bearing horizons.

5. Relation, if any, of ore bodies to the jointing system.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

PETROLOGY OF RESERVOIR ROCKS.

Sir: The article appearing in ECONOMIC GEOLOGY for August, by A. W. Lauer, on the "Petrology of Reservoir Rocks and its Influence on the Accumulation of Petroleum," is of particular interest in that a phase of the subject is considered that heretofore has been almost entirely ignored in discussions on the accumulation of oil and the capacities of reservoir rocks. However, in regard to oil sands and sandstones at least, I am of the opinion that the relative importance of "induced" and "original" porosities is much exaggerated, and I can not agree with the writer that induced porosities in oil-bearing sandstones (cracks, joints and fissures) "entirely overshadows the original porosity of an interstitial nature," nor that these fractures of a supercapillary nature can be called in to explain away the difficulties in accounting for the accumulations of oil in sands and sandstones.

Had Mr. Lauer tested his specimens of oil sands, probably he would have been surprised at their porosity of an interstitial nature, and had he applied gas under pressure, he would have found no trouble in expelling much of the oil that the specimens of oil sands could imbibe. In the preparation of Bulletin 148, for the Bureau of Mines (in press) I had occasion to investigate the capacities of oil sands and the recoveries of oil from them. The outstanding facts shown by the compilation of data on these subjects, and by laboratory experiments on the expulsion of oil from sands and sandstones, was that the actual recoveries from

the oil sands have been far less than their capacities conservatively estimated from their probable interstitial porosities. The difficulty lies not in accounting for sufficient pore space in the oil sands in which the oil produced from them could have been held, but to explain why the yields have not been greater. So far as the recovery of oil from sands and sandstones is concerned, it is unnecessary to call in induced porosity, and this applies equally to loose sands like those of Kern River, California, and to the cemented oil sandstones of the Appalachian fields.

Speaking of induced porosity, the author says: "If strongly cemented, the sandstone will yield by broader folding, or be definitely fractured, jointed or broken," and, referring to the same type of sandstone, "interstitial space may become almost negligible, and cracks, joints and fissures become the dominant form of porosity."

The general experience in the oil fields has certainly been the reverse of what is to be inferred from these statements, and is expressed in another quotation from the author relative to Washburne's theories on accumulation, "with especial reference to one widely observed fact, namely the occurrence of oil in the more porous parts of a sand reservoir, in preference to other portions." The drillers have recognized this fact and look for the soft and most porous parts of the oil-bearing sandstone which they term "pay streaks." These are generally the most productive, whereas the tight varieties are usually least productive and often are reported as dry, though directly overlying or underlying productive pay streaks. The loose sands of California whose porosities are entirely interstitial have been far more productive per acre foot than the cemented sands of the eastern fields, though some are composed of grains so fine that their pores are actually smaller than in many of the coarser cemented oil sands of the Appalachian fields.

Were fractures of supercapillary size of the greater importance, wells in hard cemented sandstones would yield oil more readily than wells in soft sands or sandstones whose oil contents would be contained in capillary pores that would offer greater resistance to expulsion. Such, however, is not the fact, for the

tight sand wells are universally recognized as generally of slow yield, whereas wells in soft, porous or coarse sands are commonly of large initial yield but rapid decline, provided the oil is not exceptionally viscous, as in some California fields.

Field evidence is on the whole against there being much extensive fracturing across the bedding, which would provide intercommunication between various layers of the sands. It is not uncommon for a well to show but a small production till deepened a few feet, or even inches, through a dense layer into a more porous layer in the sand, or to be free from water until deepened a little. The evidence points strongly to most sands offering much greater resistance to movements of oil, gas or water vertically through the sands than along their bedding, which would not be the case were oil sands commonly fractured in the manner contended.

The average interstitial porosity of consolidated oil sandstones is certainly not less than 15 per cent. (see Bulletin 148, Bureau of Mines), and even the densest building sandstones seldom show porosities as little as 5 per cent. For the induced porosity to equal this average interstitial porosity, the fractures on a rectilinear system would have to aggregate nearly an inch of open space in every foot laterally along the bedding. Obviously, this is not the fact nor can it be reasonably postulated that induced porosity can ordinarily even approach the original porosity. The Berea grit is cited as an example where the interstitial spaces appear inadequate to store and yield the oil recovered from it, yet tests of the Berea grit quarried for building stone showed porosities of 15 to 20 per cent. Oil is forced into the well by gas rather than drains into it, and experiments have shown that much of the oil is readily expelled by compressed gas or air from specimens of fairly tight sandstones.

Personally, I do not remember having seen fracturing sufficiently extensive along the outcrops of sandstones where, due to weathering and slipping, more fracturing would occur than underground, to warrant the statements regarding the relative importance of induced porosity. Outcrops of oil impregnated Cow Run sand along the Muskingum River in Ohio, showed

very little fracturing though it was still producing oil, after fifty years, from wells located a few hundred yards back. Along the outcrops of hard oil-bearing sandstones in Ventura County, California, the fracturing is not so open and extensive as to warrant the belief it could exceed the original porosity though folding had been extreme. Moreover, the wells of Ventura County are far less productive than in other California fields where folding and fracturing has been less extreme and no cementing has taken place in the oil sands. Quarries, though showing some jointing and fracturing in the sandstones, hardly support Mr. Lauer's contentions. I have observed no such universal fracturing in the wonderful exposures of sandstones in the arid regions of the western states. It is not shown in the perfect geologic section of the Grand Canyon of Arizona. In most of the oil fields producing from cemented sandstones, the folding has been so slight that much fracturing is hardly to be expected.

I doubt whether fissures often "serve as trunk channels" in oil wells. I hardly think the favorable effects of shooting are generally the result from cracks being opened into fissures already existing in the sandstone nearby. To form open fractures by shooting, some relief by compressing the sandstone or lifting the overlying formations seems necessary. To me, neither seems probable. Upward relief would mean not only lifting the dead weight of the overlying formations, but overcoming the bridging effect and the inertia. By shooting, the hole is enlarged by breaking off fragments from the face of the sand, or pulverizing it. Experience has shown that a large hole is somewhat more productive than a small one. Besides this effect, I am of the opinion that the gases penetrate the pores in the sandstone at the moment of the explosion and as soon as the pressure in the hole has been sufficiently reduced by the escape out of the hole of most of the gases generated, these hot gases return into the well violently, bringing oil with them and cleaning out the sand pores; in an old well, the waxes; in a new well, the mud driven in while drilling. The flow of a shot well, starting some minutes

after the moment of explosion and continuing for a short time, apparently is caused by the returning gases, and ceases when they expel themselves from the pores in the oil sand.

The fact that many inaccurate estimates of the productiveness of California properties have been based on calculations of the interstitial porosity of their oil sands, can be traced as much, if not more, to erroneous factors of recovery, arbitrarily assumed, as to mistakes in estimating the capacities of the oil sands, and can hardly be used as an argument against the value of considering the porosities of oil-bearing formations. I agree with the writer, however, that production curves provide the more dependable means of estimating future productions of wells with our present limited knowledge of oil recovery.

I do not see how Mr. Lauer can reconcile with the facts his conclusions that supercapillary fractures have been the potent agents in permitting the migration of oil and its stratification with gas and water in accordance with their relative specific gravities. The same accumulations of oil have taken place in the loose sands of California where no such supercapillary channels could exist. There, the oils range from viscous tars almost as heavy as water to oils of over 50° B., and some of the sands have capillary pores finer than in some of the cemented sandstones of the eastern fields, yet apparently the oil always rose in the sand beds till prevented from further upward migration by reaching the crest of a dome, a fault, unconformity or a plug of asphalt along the outcrops of the sand where the structure might be monoclinal, plunging syncline or anticline. Accumulation took place in California without the aid of supercapillary fractures, so why should they be necessary to explain accumulations in eastern fields. Moreover, is it not likely that the migration and concentration of the oil in eastern fields took place during the long geologic periods that probably elapsed before cementation of the sands occurred, and while they were still unconsolidated, as they still are in the principal California oil fields?

JAMES O. LEWIS.

BY PERMISSION OF THE
DIRECTOR OF THE BUREAU OF MINES.

REVIEWS.

Building Stones and Clays. By CHAS. H. RICHARDSON. Published by the author, Syracuse, N. Y. 8°; 437 pp.; 303 halftones, 10 figs.

The subtitle of this work states that it is for architects and engineers; to this might be added that it should prove of interest to all engaged in the stone, building and brick industries.

The writer begins by an account of the important minerals of which the building stones are composed, which is given in as simple and non-technical a manner as possible. This is followed by a chapter on the physical properties and weathering of stones and the various tests that may be applied to them to determine their excellence for constructional purposes. The author then takes them up in the following order, granites, limestones and marbles, sandstones, shale and slate, serpentine and steatite, and to each of these a chapter is devoted, in which the chief quarries in the United States and other countries are briefly described, together with an account of the stone which they furnish. He states also the methods of quarrying, of dressing the stones, and gives the results of various tests upon them. The latter part of the book contains chapters on clays, and their properties; on mining and washing clays, on building bricks, on concrete and cement, and on artificial stone.

The book appears to be of well-selected matter for a general reference work. It is very thoroughly illustrated with views of quarries, of buildings, monuments, etc., to exhibit the use of particular stones, and with photographs of the rock surfaces to show their grain, fabric, etc. Those of buildings, and of the quarry and dressing industry, are excellent, those of the stones are mostly as good as the average of such illustrations, which is to say poor, for it is generally difficult, and often impossible, in a black and white halftone, no matter how well the photograph has been taken, to satisfactorily depict rock surfaces so that they have much meaning.

A list of pertinent literature will be found useful for those who desire more information on particular subjects.

L. V. P.

RECENT LITERATURE OF ECONOMIC GEOLOGY.

COMPILED BY

R. E. SOMERS.

GENERAL ECONOMIC GEOLOGY.

Economic Geology in 1916. By ADOLPH KNOPF. Eng. & Min. Jour., Vol. 103, p. 64, 1917.

A review of interesting literature and investigations in 1916.

Railway Geological Department. By J. H. WATKINS. Eng. & Min. Jour., Vol. 102, p. 931, Nov. 25, 1916.

Points out the function of the geologist in connection with railway development and service.

On the Measurement of Temperature in Bore Holes. By JOHN JOHNSTON and L. H. ADAMS. Econ. Geol., Vol. XI., p. 741, Dec., 1916.

Several methods are discussed, and some new results obtained with an electrical resistance thermometer are presented.

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Notes on Rare Mineral Occurrences. By RICHARD C. HILLS. Proc. Colo. Sci. Soc., Feb., 1917.

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The Evidence of the Oklahoma Oil Fields on the Anticlinal Theory. By DORSEY HAGER. Bull. A. I. M. E., Feb., 1917, p. 195.

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The Norfolk Oil Shales. By W. FORBES-LESLIE. Chem. Tr. Jour., Oct. 21, 1916.

Report on the Oil Shales of Impendhle County, Natal. By A. L. DU TOIT, So. Afr. G. S., 1916.

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Some Problems in South African Geology. By PERCY A. WAGNER. So. Afr. Min. Jour., Mar. 24 and 31 and Apr. 7, 1917.

Mineral Prospects in Fergus County, Mont. By O. W. FREEMAN. Eng. & Min. Jour., Vol. 103, No. 15, p. 660, Apr. 14, 1917.

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Mineral Resources in Ill. in 1915. By H. J. SKEWES. Bull. 33, Ill. State Geol. Surv., 1916.

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Deals with copper, lead, zinc, tin, and aluminum.

SCIENTIFIC NOTES AND NEWS

ALFRED E. BROOKS reports good health and plenty of work in France.

J. B. TYRELL has been nominated for the presidency of the Canadian Mining Institute.

O. E. LEROY, formerly economic geologist of the Canadian Geological Survey, has died of wounds in France.

AUGUSTUS LOCKE is at present near Mazatlan, Mexico, engaged in geological work.

R. J. JOHNSON, of the University of Pittsburgh, and Frederick Ehrenfeld, of the University of Pennsylvania, have been appointed Commissioners of the Topographic and Geologic Survey Commission of Pennsylvania.

THE MEETING of the Geological Society of America in St. Louis, December 27–29, 1917, was attended by about eighty members. Among those present were F. D. Adams of Montreal, A. P. Coleman and C. W. Knight of Toronto, and J. F. Kemp of Tulsa, Okla., whom we are glad to say is much improved. Mr. E. O. Ulrich was the sole representative of the survey. The absence of eastern geologists was noticeable; even Chicago and Madison had no representatives. Among the papers read was one by Professor W. A. Tarr on the lead deposits of southeastern Missouri, in which an origin by ascending waters was suggested, one by Professor R. H. Johnson on the absence of water in dry sandstone beds. There was also a paper on oölites by Messrs. Van Tuyl, Tan and Bucher, and a note on glauconite in limestone of Missouri by Professor Tarr.

THE GEOLOGICAL EXCURSION in connection with the meeting was to the southeast Missouri lead fields under the direction of Professor W. A. Tarr. The ore deposits at Flat River, and Mine La Motte and North American Mine in the vicinity of Frederickton were visited. In the party were R. M. Bagg, A. P. Coleman, C. W. Knight, E. H. Kraus, F. R. Van Horn, L. G. Westgate.